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APPLICATION OF REMOTE SENSING TO SELECTED PROBLEMS WITHIN THE STATE OF CALIFORNIA

A report of work done by scientists of three campuses of the University of California (Berkeley, Santa Barbara and Riverside) under NASA Grant NSG 7220 from the NASA Office of Space and Terrestrial Applications, Technology Transfer Division

Annual Report
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UNIVERSITY OF CALIFORNIA, BERKELEY

APPLICATION OF REMOTE SENSING
TO SELECTED PROBLEMS WITHIN THE
STATE OF CALIFORNIA

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CHAPTER 1

INTRODUCTION

The primary goal of virtually all of the remote sensing-related research that is being conducted in California at the present time is that of gaining the acceptance and use of modern remote sensing technology by the managers of California's natural resources. Consistent with the goal, the overall objective of work done under this grant is to demonstrate, by means of specific case studies, that information derived from the use of modern remote sensing techniques can lead to the development and implementation of more intelligent resource management measures than would otherwise be possible. All of our case studies deal with applications that can be made of remote sensing in California, while not excluding their application, with suitable modification, in other states as well.

There are two responsibilities commonly assigned to those who manage the natural resources of the state of California: (1) that of producing, within the area for which they have management responsibility, the maximum amount of various goods and services (food, fiber, recreation, etc.) and (2) that of enhancing, on that same area, the quality of the environment, including its overall aesthetic appeal, and the quality of its water, atmosphere, wildlife habitat, etc. There is an increasing demand that this two-fold responsibility be fully met in California, and it is in this respect that the use of modern remote sensing technology can play a vital part.

As a first step toward the more detailed defining of the resource manager's two-fold responsibility, policy decisions usually must be arrived at relative to the uses that should be made of the natural resources in any given area. Thereafter, laws usually are made at the municipal, county, state, and federal levels that will be in consonance with those policy decisions. Next, and also in keeping with those policy decisions, resource management plans must be developed and implemented. The making of these plans requires, in turn, the acquiring of information about the resources that are to be managed -- usually in the form of resource intervals, so that the resource manager will know at all times, suitable frequent intervals, so that the resource manager will know at all times, both the amount and the condition of each kind of resource that is present within each portion of the area for which he has management responsibility. As will be apparent from the studies dealt with in this report, it usually is through the use of modern remote sensing technology that the required resource-related information can best be derived.

In many cases, there is insufficient knowledge on the part of the resource managers of how remote sensing might be applied, but they have stated that, given one or more appropriate demonstrations of such applications, they would then hope to make remote sensing an integral part of their overall resource management process. From among the many possible cases fitting this description, only a few are dealt with in this progress report. These "case studies" are being performed by our remote sensing scientists on the Berkeley, Santa Barbara, and Riverside campuses, respectively, of the University of California. A description of progress made to date on these case studies will be found in Chapters 2, 3, and 4, respectively, of the present Progress Report.

As will be apparent from a reading of this document our integrated project continues to entail two major but inter-related categories of activity:

(1) Basic research, as necessary to develop, in each problem-oriented situation, a remote sensing-derivable classification scheme that will enable us to help the resource manager solve the particular resource inventory/management problem that is being addressed, and (2) Applied research, as necessary to ensure that the resource manager with whom we are cooperating in any given instance is in full agreement that our resource classification shceme provides him with the information that he needs in order to solve his particular resource management problem. The applied aspect of our research is further designed, in each instance, to ensure the transfer of this technology to the user. We consider ourselves to have been successful in this endeavor when the user not only understands the technology that we have helped to develop but also accepts it to the extent that henceforth in all appropriate instances, he actually uses it, (instead of his previously-used methods), as the information base from which to arrive at and implement resource management decisions.

The map of the state of California, comprising Figure 1, on the following page, has been annotated in order to indicate the specific remote sensing sites, both past and proposed, of our 3-campus project.

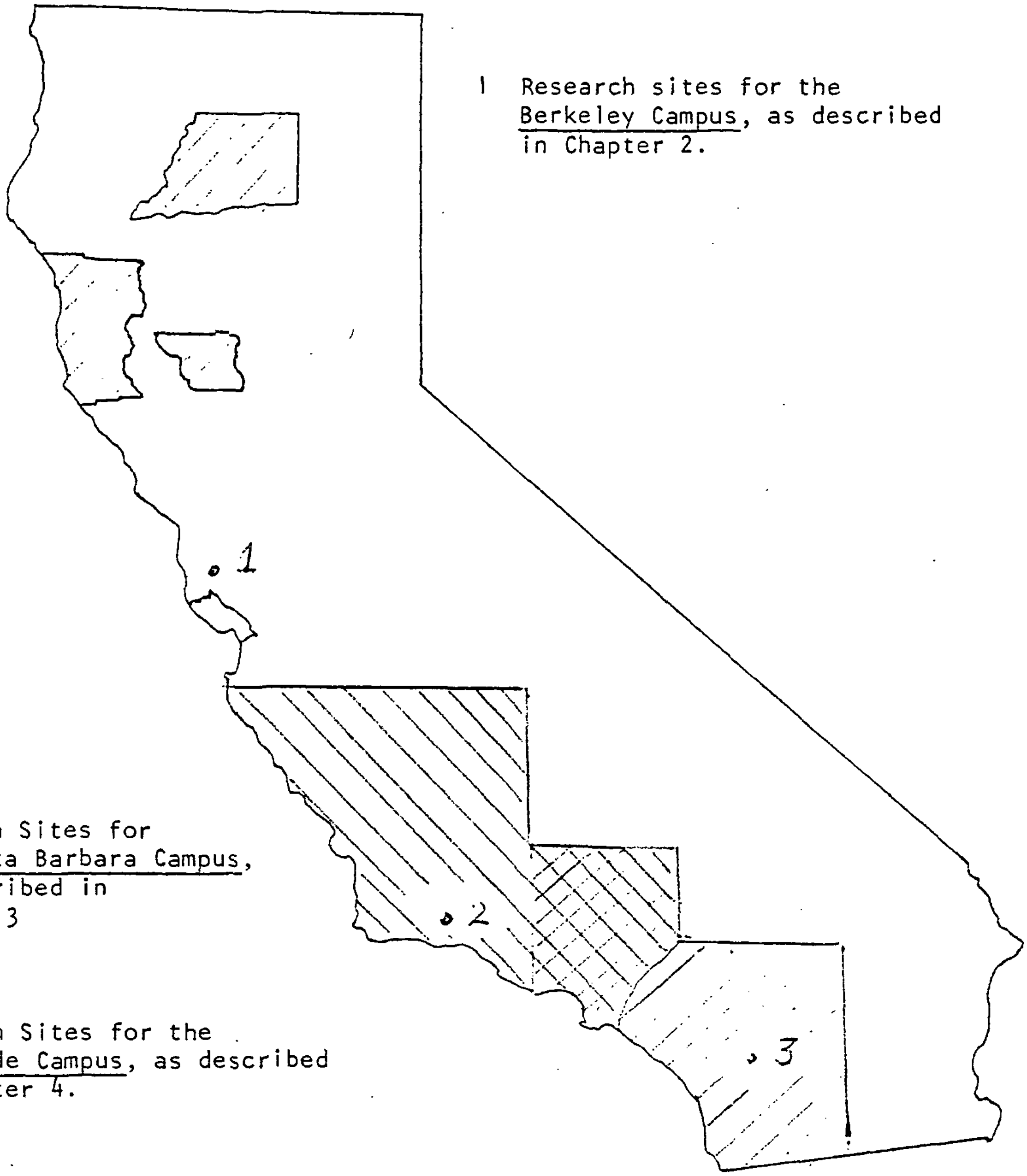

Figure 1. Map of the State of Claifornia showing general locations of study areas for remote sensing scientists of the Berkeley Campus (1); the Santa Barbara Campus (2); and the Riverside Campus (3) of the University of California.

In the Table of Contents for Chapters 2, 3, and 4 at the beginning of this Progress Report, a clear indication is given of the specific Case Studies that we have engaged in during the past year on the Berkeley, Santa Barbara and Riverside campuses, respectively. It should be emphasized that the true acceptance of modern remote sensing technology is a primary goal of each of the projects listed there. Chapter 5 is included because it summarizes the activities that our group has been pursuing recently with funds other than those provided under this NASA-funded grant. Those activities are included because work that we have done under the grant has made it more feasible for us to do this ancillary work.

CHAPTER 2

NORTHERN CALIFORNIA STUDIES

CHAPTER 2

NORTHERN CALIFORNIA STUDIES

INTRODUCTION

Throughout the past year, personnel from the Remote Sensing Research Program (RSRP), University of California, Berkeley, have been working closely with personnel from wildland management and county planning agencies in northern California. The objective of this research has been to demonstrate the proper integration of remote sensing and ancillary data to meet the information needs of those who manage natural resources. Only after these information needs have been met can the land managers develop and implement plans for the wise use of all wildlands and associated natural resources under their jurisdiction.

The key to our success in conducting this research has been the active participation of the land managers themselves in the analysis of the remote sensing and ancillary data. Because of this participation we are finding that the field personnel are not only acknowledging the potential usefulness of modern remote sensing technology, but are also making extensive use of the fact that remotely-sensed data can fulfill and/or supplement many of their information needs in a cost-effective manner, thereby enabling them to make and implement resources management decisions more intelligently than would otherwise be possible.

The following sections document the work being conducted in Mendocino, Colusa, Shasta and Santa Cruz Counties, California (see Figure 1), through the cooperative efforts of resource managers and personnel of our Remote

Figure 1. Location of Mendocino, Colusa, Shasta and Santa Cruz Counties in northern California. Investigations are being conducted here by personnel of the Remote Sensing Research Program, University of California, Berkeley, to demonstrate the usefulness of remote sensing-derived information for planning and implementing wildland management programs in selected sites within these counties.

Sensing Research Program (RSRP). Part I describes preliminary studies designed to quantify wildland fuels in Mendocino County, California. This work is being conducted jointly with fuel management personnel of the Forest Service's Covelo Ranger District. Part II describes the first computer-assisted application of Landsat and ancillary data for general planning in Mendocino County, California. This project will be completed by mid-summer 1981. Part III describes the application of Landsat and ancillary data for coordinated resource planning within the Stonyford Resource Conservation District, Colusa County, California. This project will be completed also by mid-summer 1981. Part IV describes preliminary investigations for the application of a State-wide Landsat data set to assess the hazardous buildup of fuels in wildland areas of Shasta County, California. Finally, Part IV describes the construction of a multiband digital data bank for Big Basin State Park, Santa Cruz County, California. Partial funding for the latter project has been made available by the California Department of Parks and Recreation. This past year, our research efforts have concentrated on Parts II, III, and V. The scope of the projects outlined in Parts I and IV is being redefined because of new federal and state funding limitations.

After reading these five sections, the reader will see that the common goal of these studies is not just the mapping of various wildland resources, but the quantification of these resources as well. The process of quantifying map products which have been derived from remote sensing data requires extensive field work. In order to make this ground data collection effort more efficient, we have developed, or will develop, digital information systems for each study area. These systems can be used for (1) allocating ground samples in a statistically valid manner, and (2) expand the limited ground sample data in a logical process throughout the area of interest. We feel strongly that any remote sensing studies that are being conducted in wildland environments must use this information systems approach if the current information requirements of wildland managers are to be met in a cost effective manner.

PART I

QUANTIFICATION OF WILDLAND FUELS IN MENDOCINO COUNTY, CALIFORNIA

by

Andrew S. Benson

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PART I

QUANTIFICATION OF WILDLAND FUELS IN MENDOCINO COUNTY, CALIFORNIA

1.0 Introduction

During the past four years, personnel from the Remote Sensing Research Program have worked closely with fuel specialists in Mendocino County in order to provide Landsat-based maps of wildland fuel hazards within the County. While the knowledge of where these hazards exists is vital to fire control personnel for allocating fire suppression resources the quantification in terms of tons/acre is also of primary interest so that these fuels can be managed in an intelligent manner. These data provide the information needed to determine whether or not a fuel type should be modified, and if so, how it should be modififed. In addition, these data may prove to be useful for studies that are not being carried out throughout California in which investigators are seeking to determine the possibility of using wildland "waste" products, such as brush, hardwoods, and logging slash, as an alternative to energy derived from fossil fuels. Therefore, the quantification of Landsat fuel-classes in terms of tons of material/acre is a subject of increasing interest to fuel management specialists in Mendocino County.

Regardless of the fuel management objective -- reducing fire hazards or harvesting energy resources -- the data from which the needed information is derived must be collected in a timely and cost effective manner. The data must be current in order to meet changing policy decisions and to account for the constant change in vegetation composition; the data must be collected inexpensively because the intrinsic value of the fuel is either negative, as in the case of fire hazards, or low, as in the case of an energy resource. Our work to date on this project prompts us to predict that Landsat data used in conjunction with large scale aerial photos and a limited ground sample soon will prove to be an ideal data source in relation to these requirements.

2.0 Procedure for Quantification of Wildland Fuels

The procedure that was originally proposed to be used in quantifying the fuels in northeastern Mendocino County is as follows:

1. Define ground sampling frame. The sample frame is limited to the National Fire Danger Rating System fuel class F (chamise, manzanita, and chaparral) as defined on classified Landsat data.
2. Procure large scale sample photography. The U.S.Forest Service will obtain large scale (1:1000) 35 mm photography of a number of transects which represent Class F. These photos will be used to define ground sample plots, to quantify ground cover, and to assist in field operations.
3. Collect ground data. Field crews from the U.S. Forest Service will collect ground data from a sample of the large-scale photo plots. These ground data will be used to estimate fuel loads in tons/acre.
4. Correlate ground, photo and Landsat spectral classified data. Statistical relationships will be developed between the three sample stages.
5. Expand fuel loading estimates to management units. If valid statistical relationships can be developed in (4) above, the fuel loading estimates will be expanded to applicable fuel management units such as the Watershed Management Units and the

Covelo Ranger District.

6. Implement final modification plans. Based in part on the information from the fuel loading maps produced in (5), fuel modification programs will be implemented by personnel of the U.S. Forest Service and the California Department of Forestry in northeastern Mendocino County.

3.0 Results to Date

During the past reporting period, our research efforts have concentrated on items 2 and 3 above. Four flight lines of large scale photos were flown both in large scale/stereo triplets, to provide ground sample points, and in small scale complete coverage for field navigation purposes. On the center photo of the stero triplet, a .10 acre circular plot was annotated. Of the 36 plots so annotated, 15 have been visited in the field where various field measurements were recorded. In addition, the standing brush on two .001 acre circular "mini" plots was clipped for subsequent lab measurements. Based on these measurements, tons/acre figures are calculated. The draft for both the field and lab procedures is given in Appendix A along with a letter from Andrew Benson (RSRP) to Gary Biehl (USFS Covelo Ranger District) regarding suggested changes in the draft.

Unfortunately, personnel cuts on the Forest Service staff have effectively halted the lab work that is needed to make the quantification between .001 acre plots and the .10 acre photo plots. Such data must, in turn be correlated with the Landsat classes. Personnel are expected to be available this summer, to continue this work.

4.0 Work To Be Done During the Coming Year

At the time of this writing, the scope of the fuels quantification work outlined in section 2 will be reduced. Instead of expanding sample data to the entire Covelo Ranger District, we must concentrate our research to a 3000 acre management compartment. The Forest Service will obtain 100 percent large scale photo coverage of the compartment with their 35mm camera system. Ground samples will be allocated, based on the Landsat classified vegetation-fuels map for the compartment, and ground measurements will be collected and correlated with the Landsat spectral data.

APPENDIX A

BRUSH INVENTORY (Draft)

Field and Laboratory Procedures

BRUSH INVENTORY

FIELD PROCEDURES

by

Gary Biehl
Covelo Ranger District
Mendocino National Forest

Establishing 10th Acre Plot Centers:

Use the provided aerial photography to locate the plot center. Mark the location of the plot center on the ground with a survey stake. The plot center is shown as a pinprick through the aerial photograph.

Establishing Sample Line:

Select a plot direction from the random compass bearing chart. Starting from the plot center, proceed at the selected compass bearing for 37 feet, 3 inches, and establish the outside edge of the plot. Mark this point on the ground with a wooden stake and with a small black dot on the aerial photograph of the plot.

Stem Count:

Establish the borders of the plot by using a tape or cord 37 feet, 3 inches long and walking around the circumference of the plot. While doing so, tally all of the basal stems within this area by species and record in the field report.

Establishing 1000th Acre Mini Plots:

Establish the mini plot centers by measuring 16 feet, 7 inches, from the plot center along the plot directional line, and 3 feet, 9 inches, from the outside edge of the plot toward the plot center along the directional line.

Mark each plot center with a survey stake. The center of mini plot A will be 3 feet, 9 inches, from the outside edge that was previously marked on the aerial photo (see Figure A-1). Starting with plot A and ending with plot E, proceed as follows:

Determining Crown Volumes:

Use a nail with a 3 foot, 9 inch cord attached to outline the circumference of the mini plot. Within this mini plot area, determine by each species group the crown diameter and crown height. Assign a crown number to each group of basal stems that form a crown group. Crown diameters are determined by averaging two diameters taken at rignt angles (90°) to each other. If the crown is too irregular to sample by this method, imagine two or more circles over the crown and find the average diameter of each.

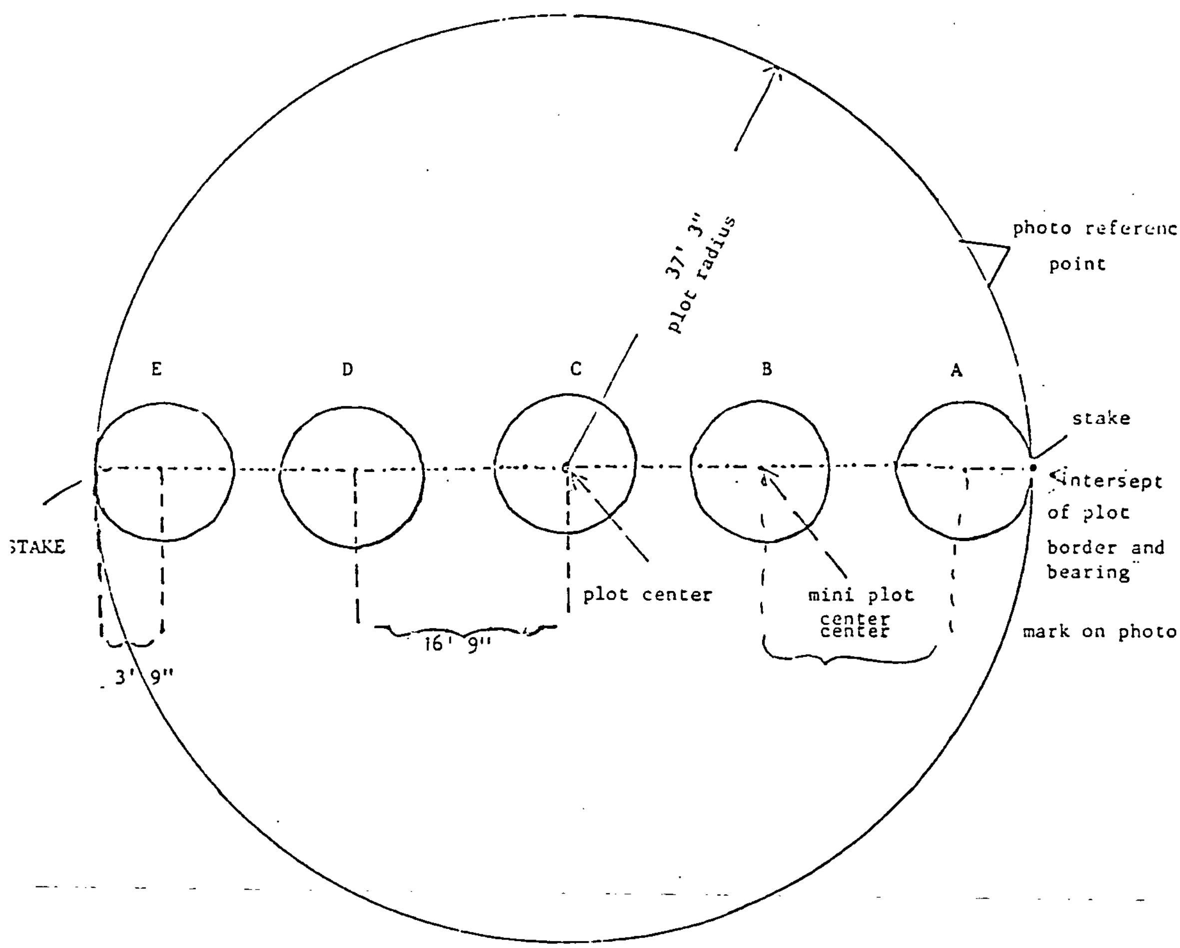

Figure A-1. Plot layout for brush inventory field procedures.

The crown height is measured from the ground to the top of the crown group as shown in figure A-2. Record on the field report the mini plot letter, crown group #, species, crown diameter, and crown height for each crown group within the mini plot.

Collection of Samples:

Clip all basal stems that fall within the boundary of mini plots A and E. If no vegetation occurs, move to the adjacent plot until a vegetation sample is available from 2 mini plots. For each crown group, measure the diameter of a basal stem 2 cm, above the cut and record on the field report. Mark this stem with a piece of flagging. Group the cut materials into sacks by crown group. Be sure to include the plot # and mini plot crown #, and number of bags containing this crown # (example, bag 3 of 4) on the sack.

Remarks:

Note if the plot has been disturbed by skid trails, roads, burns or other activities. Also note any natural condition that might affect the stand (e.g. slides) or anything unique to the site.

Since this is a pilot study, we are trying to keep a record of the time involved. Record this information here.

Other Information:

While the stakes are still in place take a picture of the plot. Include the range pole as a guide to scale. Be sure in so doing, to make the photo representative of the plot and try to photograph along the line containing the mini plots. Mark an (<) on the aerial photograph showing the location and direction of the photograph.

Before leaving the plot record the slope of the 10th acre plot and its aspect on the field report.

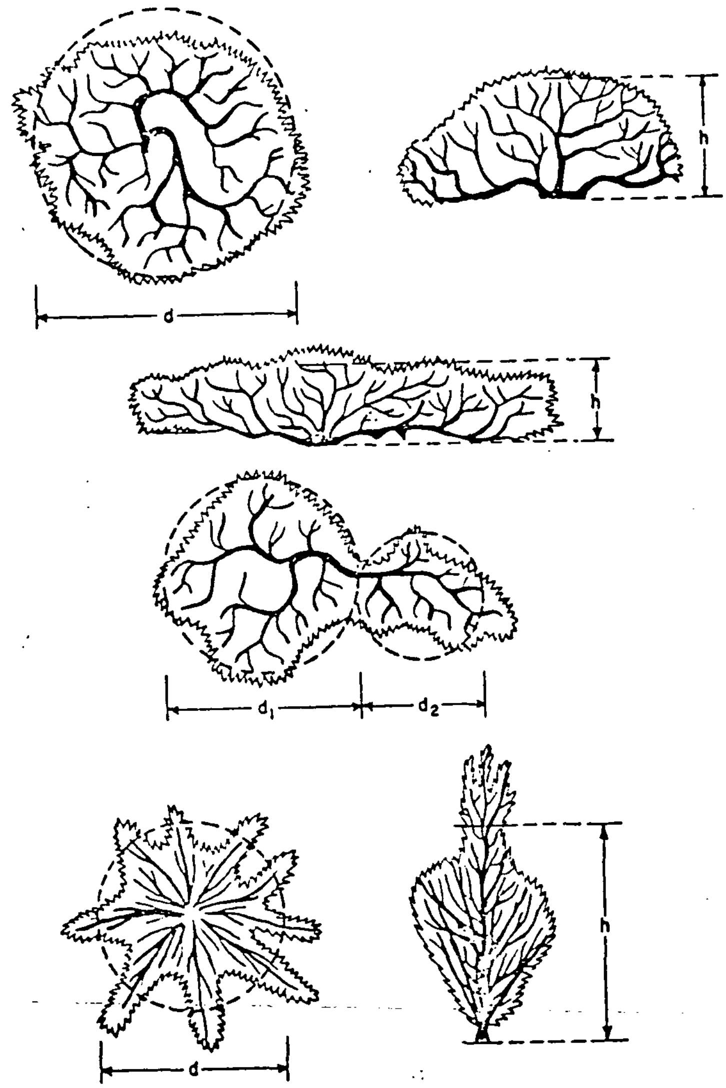

Figure A-2. Field methods for determining brush crown surface area. (From: A technique for sampling low shrub vegetation by crown volume classes by Jay R. Bentley, Donald W. Seegrist, and David A. Blakeman. Forest Service Research Note PSW-215, 1970.)

BRUSH INVENTORY FIELD REPORT

A. Assign a unique plot number starting from one and continuing as needed for each plot.

B. Record a short written statement of the general area within which the plot is located. Example: "Horse Pasture Ridge".

C. Record the Government Land Office Survey, Township, Range, and Section numbers. Example: "T21N, R11W, S12", would read "Township 21 North, Range 11 West, Section 12".

D. Record the Universal Transverse Mercator grid coordinates for the plot center. Example: 11N 21E.

E. Record the flightline number followed by the aerial photo number from the low level photography, on which the plot center can be found. Example: "F12, P13", would read "flightline 12, aerial photo number 13".

F. Record the elevation above sea level for the plot center.

G. Record the average slope in percent for the 10th acre plot.

H. Record the aspect on which the plot rests, using the following compass points: (N, NE, E, SE, S, SW, W, NW).

I. Record the distance measured from the plot center to the outside edge of the plot as marked on the aerial photo.

J. Record the random compass direction in which the plot transect will run, and record this to the nearest degree.

K. Enter the month, day, and year, on which the plot was first visited.

L. Record the species encountered within the 10th acre plot. Use a 2 or 3 letter abbreviation. Examples:

    CH for Chamise
    LOK for Live Oak
    MZ for Manzanita
    BB for Buck Brush

M. Record the total basal stem count for each species found in the 10th acre plot.

N. Record the mini plot letter (A, B, C, D, E) and assign a number starting with 1 to each group of shrubs by species within the mini plot.

O. Record the species of the crown group using the same abbreviation as in section L.

P. Record the average crown diameter of the crown group. Enter in inches.

Q. Record the average crown height for each crown group. Enter in inches.

R. Record the basal stem diameter of a selected primary stem. Mark the stem with flagging to determine in the lab the amount of shrinkage that will occur when dried.

S. Record any remarks pertinent to the growth characteristics of the plot. This might include such items as a history of the area, fire damage, mechanical treatment, etc..

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BERKELEY, CALIFORNIA 94720

24 March 1981

Mr. Gary Biehl
U.S. Forest Service
Rt. 1, Box 62C
Covelo, California 95428

Dear Gary:

I have read the draft of the Brush Inventory Procedure. Here are a few comments.

1. The .10 acre photo plots must be defined on the photo, not on the ground. In other words, we will try to draw a circle that has a reaius of 37.25 feet ground distance on the photo. Just how close this radius is to true ground distance will be a function of how well we can estimate scale. This is an important step,because in an operational mode we will have many more photo plots than we can visit on the ground. Therefore, we must establise the error involved with estimating scale on the photos if we are to derive the per acre estimates.

The Procedure could be rewriten as follows:

Establishing the .1 acre plot. Locate the center of the .1 acre circular plot, as annotated on the large scale aerial photo, on the ground; mark the plot center, as designated by a pin prick through the center of the photo, with a survey stake. Determine the average radius of the circular photo plot on the ground and record on the plot sheet. (The expected radius is 37..25 feet, but if the terrain is steep, the true plot radius may vary from 10-15 percent.) Tape the radius up-slope, down-slope, and cross-slope; average the measurements.

2. Since we have no guarantee that the photo plot has a 37.25 foot radius, the center of the mil acre mini plots should be redefined as follows:

Establishing the .001 acre mini plot. Locate the circulat .001 acre mini plot centers along the random sample line as follows:
(1) plot A and E located 3.75 feet from the outside edges of the photo plot;
(2) plot C located at the center of the .1 acre photo plot; and
(3) plot B and D at half the distance between centers CA and CE respectively.

3. The actual stem measurement techniques look good. However, using 1/64 inch increments will make all subsequent calculations clumsy. Could we convert to either the metric system or to tenths of an inch?

4. Re: Collection of Samples.I note that we are clipping all stems that fall within the mini plots A and E for subsequent diameter, length, and weight measurements. This approach could, therefore, include some crown materials that fall outside the .001 acre plot. This would inflate our per acre estimates unless there is a compensating error caused by stems which fall outside the plot and have their crown fall partially within the plot. Any thoughts on the problem? Personally, I think the errors will be compensating.

Everything else looks good. Perhaps we should get together soon and try some calculations.

Sincerely,

Andy

Andrew S. Benson
Remote Sensing Research Program

PART II

FORSYTHE PLANNING EXPERIMENT

APPLICATION OF LANDSAT AND GEOGRAPHIC INFORMATION SYSTEMS TO PLANNING PROCESSES IN MENDOCINO COUNTY, CALIFORNIA

by

Charles E. Henderson

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PART II

FORSYTHE PLANNING EXPERIMENT

1.0.0 *Introduction*

As part of ongoing research and demonstrations entitled the Application of Remote Sensing to Selected Problems within the State of California (NASA Grant NSG 7220) personnel at the Remote Sensing Research Program (RSRP), U. C. Berkeley, have developed a resource information data base for a 37,000 acre wildland area in Mendocino County, California. The development of this data base and the subsequent utilization of the DIANA (DIgital Image ANAlysis) System at the RSRP facility (Space Science Laboratory) have comprised the 'Forsythe Planning Experiment'.

The Forsythe Experiment has focused on three overlapping study areas (see Figure 2). A grid file data base has been built for each area to demonstrate the applicability of variable resolutions and degrees of accuracy. These include:

Forsythe Creek Watershed	1.1 acre resolution
Willits SE 7½' quadrangle	$30m^2$ resolution
Jack Smith Creek Watershed	$10m^2$ resolution

The majority of work has utilized $30m^2$ resolution and has been applied to the Willits SE quadrangle.

The Forsythe area was chosen because of development pressures, sensitive soil types, relatively steep slopes and a diverse pattern of vegetation. The vegetation pattern was representative of other areas throughout the country.

Five major tasks have been addressed by the Forsythe Experiment:

(1) The normalization of Landsat MSS data using digital elevation models.

(2) The Vegetation Classification of the normalized MSS data set.

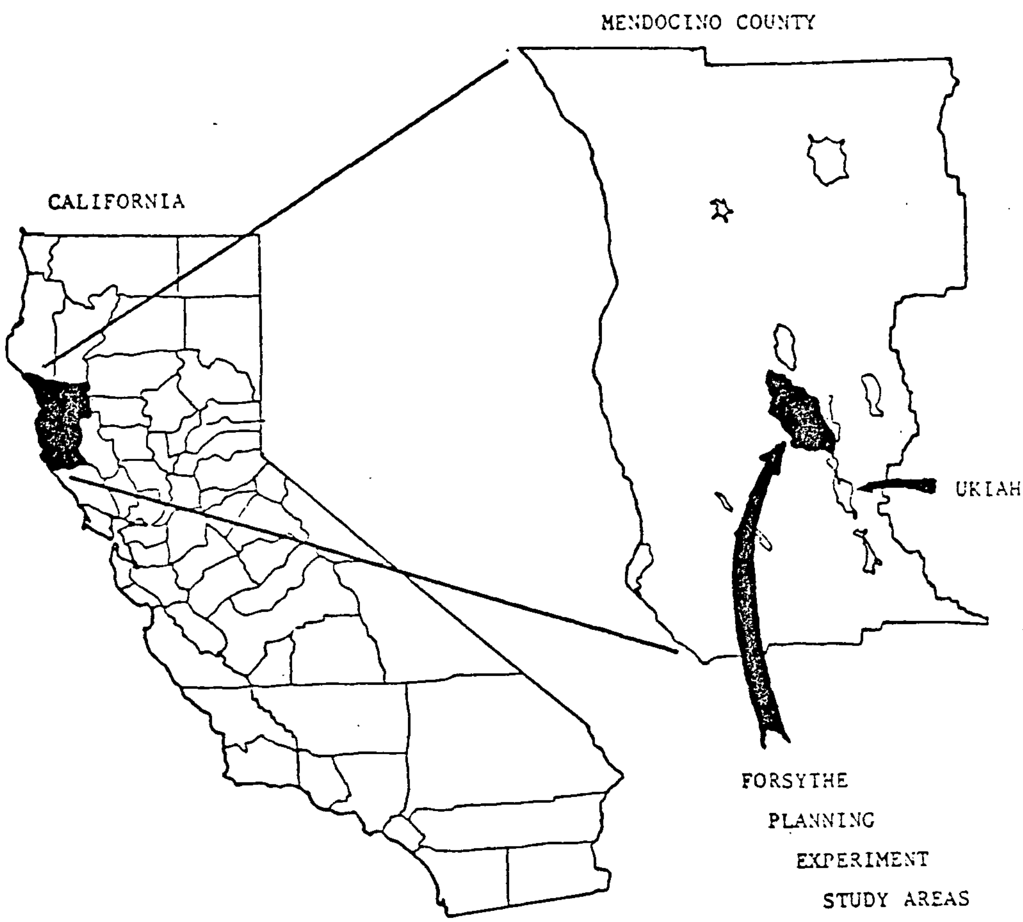

Figure 1. The Forsythe Planning Experiment Study areas are located between the cities of Ukiah and Willits in Mendocino County. Rapid population growth and resultant land development are taking place in the study area. Pressures on timber production capability, rangeland productivity, fire suppression capabilities and the self support of the County are increasing as development continues. The Forsythe Planning Experiment is a demonstration of remote sensing and geographic information system applications to the difficult problems of general and site-specific planning.

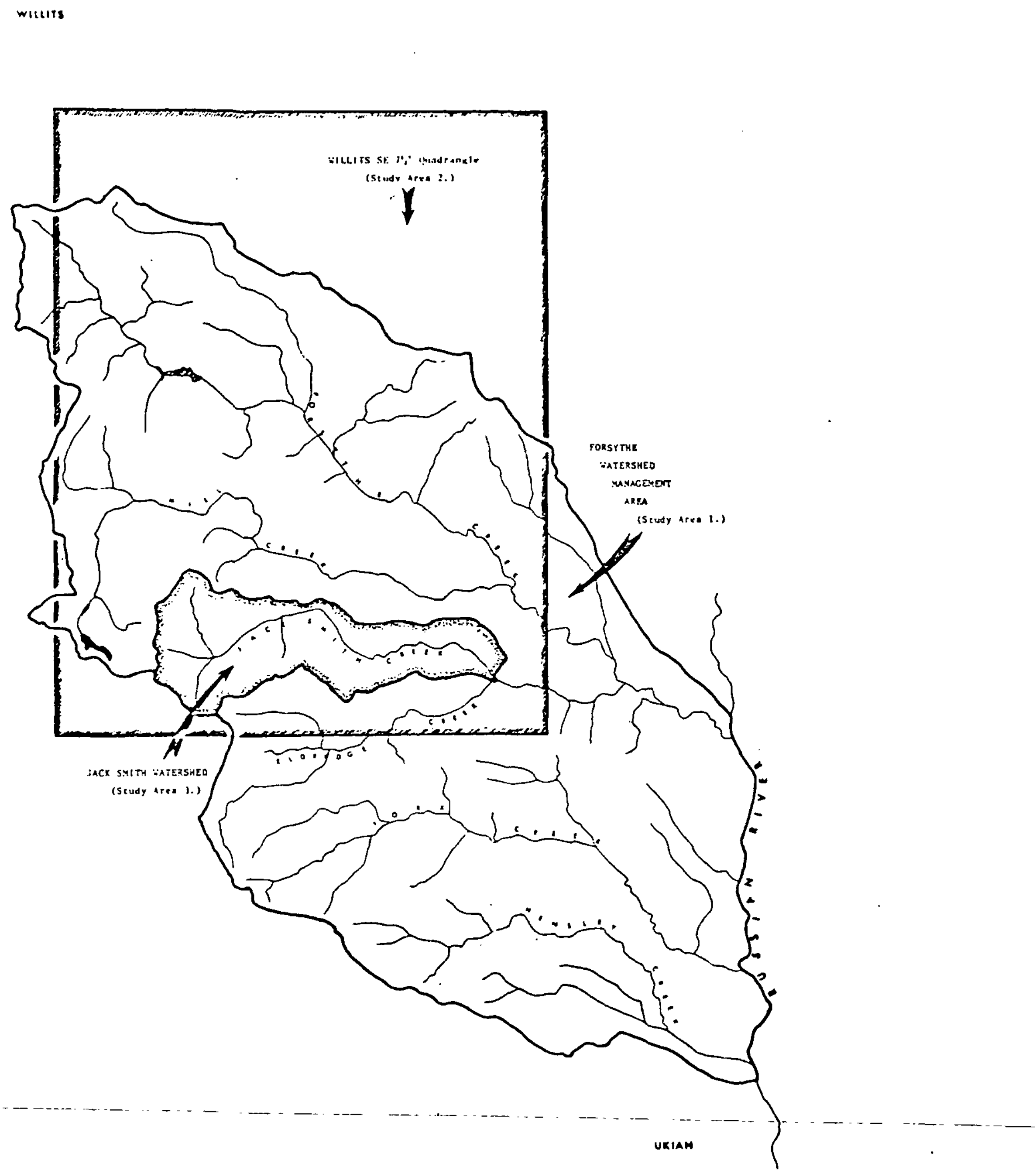

Figure 2. Three study areas, each to be portrayed by different types of information, and overlays of data, are addressed by the experiment. Study area 1, the 45,000 acre Forsythe Watershed Management Unit, is comprised of seven sub-watersheds. Study area 2 is the area covered by the Willits SE 7½' quadrangle map. This area was selected for Digital Elevation Model (DEM) coverage. Study area 3 is the Jack Smith Watershed.

(3) A report to the supervisors of Mendocino County, outlining the advantages and resource requirements of an operational GIS system - with example products from the Forsythe Experiment.

(4) An evaluation of the slope component of soil descriptions prepared by the USDA Soil Conservation Service mapping team in Mendocino County.

(5) The development of a variety of special map products for integration with the existing manual mapping system currently in use in Mendocino Countrry.

Throughout the course of this work emphasis has been placed on the development of products which could tie directly into the information gathering and utilization systems already operative in the County. Clearly, there is an accepted need to bring the various resource information users and providers in the County into an information sharing system. Recent creation of the EPI (Environmental Planning Information) Center in the County Planning Department addressed this need by creating a document library. The mapping section of the planning department has initiated a manual overlay system based on professionally prepared composite mylars for every $7\frac{1}{2}$' quadrangle in the county.

County officials are agreed that eventually a computer system will be implemented to organize and process all geographic (map) information. However, there is disagreement on the appropriate time frame within which to initiate an automated system.

The demonstration of Landsat classified data in control burning programs in northeastern Mendocino County first opened the door for large area resource data collection in the county (Cosentino, et al., 1977). Subsequently, the California Department of Forestry initiated a program of manual overlay mapping and successfully utilized a number of resource data types to determine the appropriate placement of fire-breaks and control burns, and to develop a strategy to encourage property owner cooperation in a multi-agency coordinated resource management plan (Benson, Beck, Henderson, 1979). The success of these efforts is evidenced by their continuation in the southeast portion of the county.

Bringing the technology into Mendocino has not been an "overnight success". For institutional and cultural reasons the county has moved incrementally in the direction of satellite utilization and GIS implementation. The limited resolution of Landsat data and questions about the Federal Government's commitment to an earth satellite program have not helped matters. Demonstration, assurances of consistency, and the development of professional relationships will all shape the success of this attempt at technology transfer in the future. For the present, a capability has been demonstrated. It will be up to future projects and county personnel to pick up where the Forsythe Experiment will leave off, and to use the products and methodologies demonstrated here for the overall advancement of resource management in the county.

The maps which appear in this report are examples of the final products now being prepared for the Mendocino County data base. By interfacing the image processing and GIS capability at RSRP with an electrostatic plotting peripheral, maps at a variety of scales have been produced and integrated with the base map material. Several base map-computer map combinations are included in this report.

2.0.0 Normalization of Landsat MSS Data Using Digital Elevation Models

2.1.0 Introduction

A major task of the Forsythe Experiment has addressed the problem of variable solar illumination of mountainous terrain and its effects on the spectral fidelity of Landsat MSS data. As discussed in previous reports, a 'normalization' procedure has been developed. A final description of the normalization procedure is included here.

Recent attempts to utilize Landsat data in wildland environments have incorporated ancilliary (collateral) data. These are typically formatted to a common computer file or 'data base' and often include Landsat, elevation, slope, aspect, soils parameters, and other types of resource data.

If a resource data base includes an accurate description of the topography (digital terrain model) and if the exact sun position at the time of Landsat image acquisition is known, it may be possible to model the variable illumination at the time of data acquisistion. With such an illumination model (see Figure 3), it is reasonable to suppose that a method exists to reduce the spectral variability of the Landsat data by adjusting for the variability of solar illumination at the time of image acquisition (Holben & Justice, 1980). Such a process would yield a 'normalized' image -- that is, an image for which the variability in pixel values is determined by the ground cover alone. The resulting image would then represent a flattened topography, the spectral effects of vertical relief having been essentially removed.

2.2.0 Scope of Work

In this section a methodology to 'normalize' Landsat MSS raw data using Digital Elevation Models (DEM) to correct for the effects of variable illumination is discussed.

Figure 3. Direct Solar Illumination Model (SUNSPECT)

Study Area

The test area included the entire Willits SE $7\frac{1}{2}$ minute quadrangle in Mendocino County, California. This area is comprised of a well developed dendritic stream pattern with elevations ranging from 900-3000'. Slopes range from 9% to 75%, and aspect values are distributed in all directions with a slight bias to the southeast. The ground cover is well split between native grassland, conifer (predominantly douglas fir), hardwoods (predominantly tan oak, valley oak, and black oak), and brush (predominantly chamise). The area also includes several small lakes and a relatively flat valley (Walker Valley), which is partially irrigated.

Data Base Formulation

Landsat MSS raw data acquired 27 June 1976 was reformatted to overlay the UTM 30m grid structure of the DEM for the same area. A $30m^2$ grid cell data base was compiled containing these and all subsequent image overlays. Image processing was conducted on the DIANA (Digital Image Analysis) system developed at RSRP.

Selection of DEM

Figure 4 compares two transects of an imaginary terrain as it is modeled by both Digital Terrain Tapes (DTT) and Digital Elevation Models (DEM). DTT data (used extensively in wildland resource investigations) was first developed by the Defense Mapping Agency from 1:250,000 2°X1° USGS map quads. The ETT grid file supports $80m^2$ resolution. By contrast, the DEM date is re-compiled from orthophotoquad original quad centered photography to support $30m^2$ resolution. Figure 2 clearly shows the accuracy limitations of the DTT product; the interpolation algorithm tends to fill valleys and truncate mountain tops when they fall less than 200' from the nearest 200' contour interval.

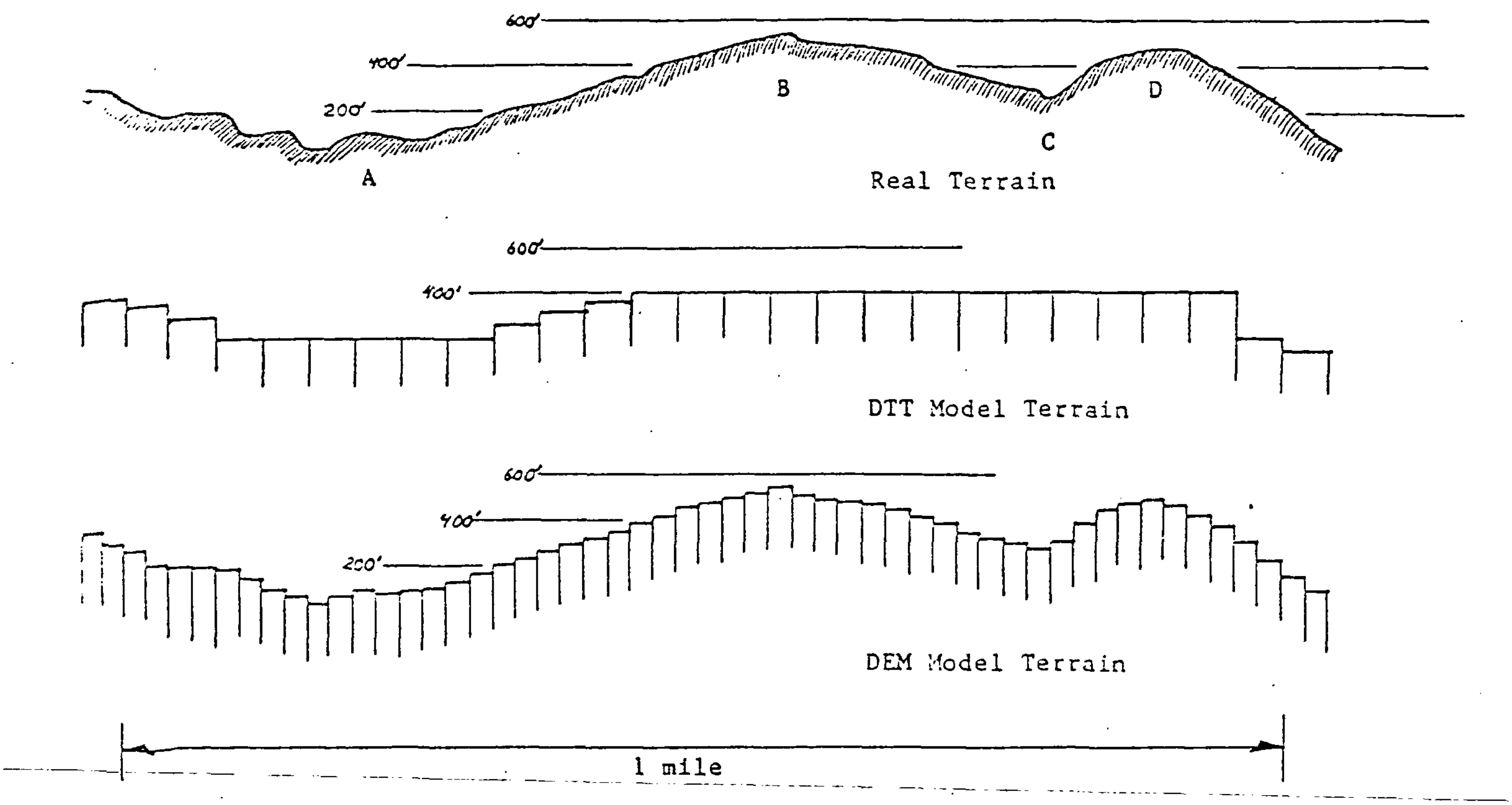

Figure 4. DTT vs. DEM terrain models shown over an imaginary transect. Note that the DTT's interpolation algorithm in some cases truncates mountain tops and fills valleys. By contrast, DEM terrain models represent the real terrain with excellent accuracy.

For the purposes of this work, the DEM product was chosen for its superior topographic fidelity.

2.3.0 Variable Solar Illumination and Landsat

The sun-synchronous orbits of the Landsat series satellites are configured such that imagery of North America is always acquired in the mid-morning hours when, even on acquisition dates near the summer solstice June 21), the sun never reaches elevations greater than 60° above the horizon. As a consequence, variability of the spectral data received for mountainous terrain and other areas of variable relief consist predominantly of variability introduced by differential solar illumination of the surface topography.

It has been shown that there is a significant decrease in classification performance due to the influence of variable illumination (Sadowski and Malila, 1977).

Holben and Justice (1980) have quantified the variability in Landsat sensor response for similar ground cover types over variable terrain. Their study showed a variation of as much as 50 counts for pixel values in the red channel (MSS 5) for a 40° solar elevation. The investigation concludes: "... a wide range of pixel values can be expected for a given cover type in mountainous areas and that, unless the topographic effect is eliminated prior to or during classification, discrimination is likely to be undertaken with poor results."

In recent years a variety of attempts have been made to integrate terrain information into Landsat classification procedures.

Echert and Campbell (1979) have quantified the variability of spectral data for a continuous vegetation complex over variable terrain. These researchers have further proposed a method for reducing classification error using ground slope and sun elevation. The advantage to this method appears to be the application of selected ground measurements (point source) to correct for variable solar illumination over an area for which synoptic slope and aspect data is not available.

Strahler and Maynard (1980) have shown that slope and aspect values can be utilized in the timer species probability classification of a forest environment. These investigators contrasted the cool, moist growing environment of northeast facing slopes with the hot and relatively dry environments of southwest facing slopes (as suggested by Hartung and Lloyd, 1969). This model was calibrated using some 73 ground samples, i.e. the coefficients for the model were fitted by an optimization algorithm. The resulting species probability distribution maps were then used as collateral data in the classification of vegetation using Landsat MSS data.

2.4.0 The Normalization 'Procedure'

The normalization procedure described here provides estimates for the relative total solar illumination (direct and scattered components) of the topographic surface area represented by each DEM picture element (pixel surface) at the time of Landsat image acquisition. This estimate is subsequently used to adjust the raw data values for each MSS band and to create a 'normalized' data set.

The total illumination of each pixel surface derives from a combination of sources including the following:

Direct Solar Illumination - derives directly from the sun without attenuation from the atmosphere.

Indirect Sky Illumination - sunlight which has been scattered (Rayleigh and Mie scattering) by molecular interaction with the atmosphere. Subsequent light impinging on a pixel surface is predominantly blue and accounts for approximately 12% of total illumination (Smith, et al., 1980).

Ground Scattering Illumination - reflected direct and indirect illumination from adjacent ground surfaces (e.g., high albedo exposed soils).

Direct Solar Illumination Component

The direct solar illumination component for each pixel is defined as the amount of solar flux which passes through the atmosphere without major atmospheric attenuation and which is reflected from the ground of a single pixel and subsequently sensed by the satellite instrumentation. Assuming the ground surface is a perfect diffuse reflector (Lambertian surface), an expression for direct solar illumination can be derived.

Under stable atmospheric conditions the direct solar illumination impinging on variable terrain of different slopes and aspects is a function of the angle of incidence (θ). The angle of incidence is the angle between the solar beam and the normal vector of the topographic surface.

θ can be calculated for a given pixel if the slope angle, aspect (direction in which a slope faces), solar zenith angle, and solar azimuth angle are known (Holben and Justice, 1980). Many investigators have demonstrated the derivation of slope and aspect values from raster elevation data, (e.g., the slope and aspect values for each pixel are commonly determined by retrieving the elevation values for the four or eight immediately adjacent pixels and determining the elevation (slope) and azimuth (aspect) values for a normal vector to the plane which 'best fits' these four elevations - see Figure 5). The solar zenith angle (90° - solar elevation) and solar azimuth angle are annotated on all Landsat scene images processed by the EROS data center.

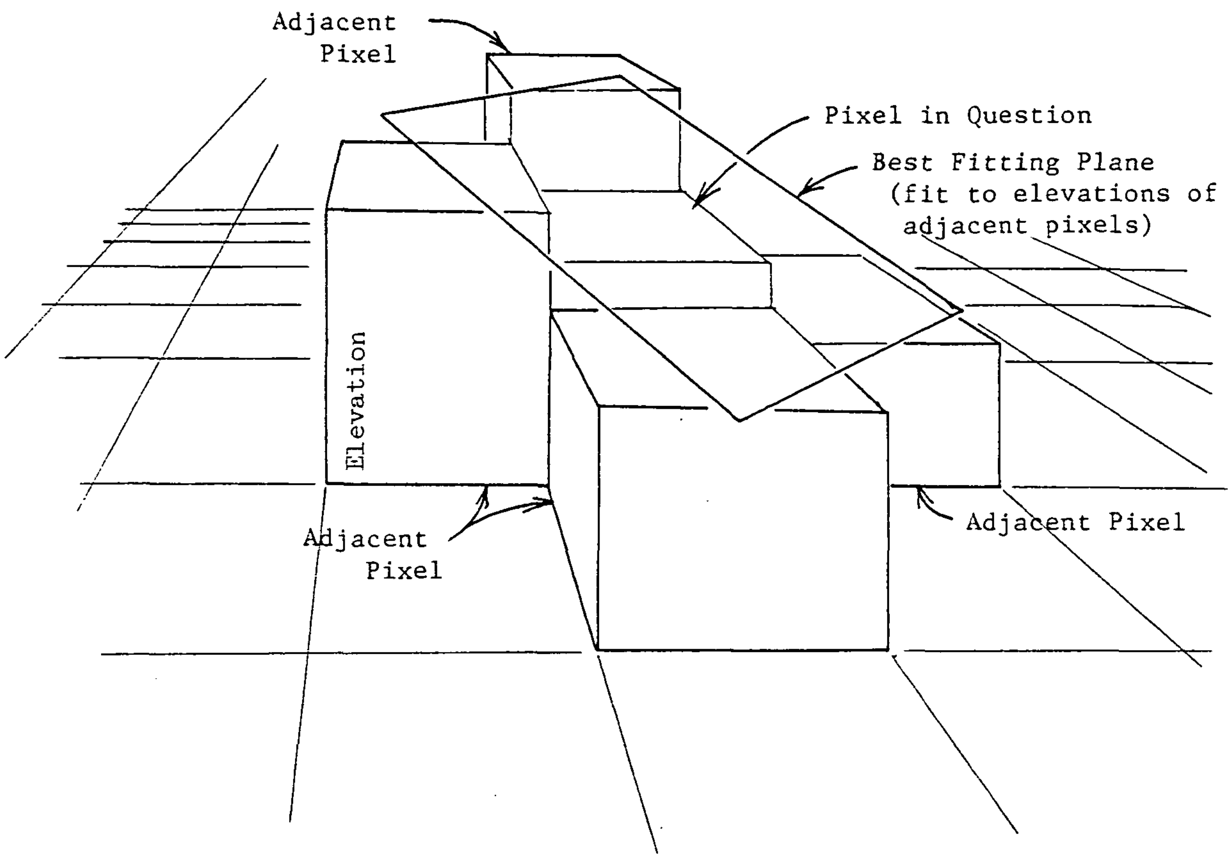

Figure 5.

DETERMINATION OF SLOPE AND ASPECT FROM ELEVATION DATA
Slope and Aspect of Best Fitting Plane assigned to Pixel in Question

As previously stated, the normalization process is aimed at the reduction of total variability through the reduction of differential illumination on mountainous terrain. Therefore, if a normalization process is successful, it is reasonable to assume that the overall variability of the normalized data set, as expressed by the CV, will be less than the CV of the raw data.

Taking this assumption to be true, the following methodology for determining the relative value of indirect illumination (c) was utilized.

1) a 1% sample of the entire data set was systematically selected using one pixel in ten for every row and column.

2) a normalization procedure was employed using

$$P'_{ij} = \frac{P_{ij}}{\cos \quad + c}$$

where P'_{ij} = *normalized pixel value for the* ith pixel in the jth band

P_{ij} = raw data pixel value

for the sample area repetitively using a variety of values for c. (c = .1 to 6.0).

3) The coefficient of variation (CV) for each value of c in each band was calculated for the resulting 'test' normalizations. The results of these repetitive tests are tabulated in table 1 and graphed in figure 6.

4) It was then postulated that the 'c' value for each band which had the correspondingly lowest CV values best approximated the proportional indirect solar illumination component for each band of the sample set. Thus the appropriate values for c were determined.

The angle of incidence θ can then be calculated using (Robinson, 1966)

$$\cos\theta = \cos s \cos z + \sin s \sin z \cos(A_s - A_p)$$

where s = slope of terrain (pixel in question)

A_p = aspect of terrain (pixel in question)

z = zenith angle of sun

A_s = azimuth of sun

If the solar flux impinging upon a surface area normal to the incident solar beam (θ = zero) is taken as unit value, the relative solar flux impinging on a surface with incident angle θ is

$$E_d = \cos\theta$$

where E_d = incident solar energy received per unit area for a pixel surface with incidence angle θ.

Assuming that the ground surface approximates a perfect diffuse reflector (Lambertian surface), light reflected toward the satellite sensor per unit area is a function of the slope (s) of the ground surface such that (Slater, 1975)

$$E_r = \cos(s) \cos\theta$$

where E_r = solar energy per ground surface unit area reflected toward a vertical sensor.

However, the total area seen as a single pixel varies with the slope of the ground surface as 1/cos(s). The <u>total</u> direct sunlight received by the sensor for one pixel is therefore

$$E_t = \frac{\cos(s) \cos\theta}{\cos(s)}$$

$$= \cos\theta$$

where E_t = total direct illumination component for a single pixel where the direct solar component for a pixel surface normal to the sun is unit value.

<u>Indirect and Ground Scattering Illumination Component</u>

Modeling for the indirect illumination component of total illumination is a more difficult task. Skylight illumination varies with the moisture (haze) content of the atmosphere and for any one pixel is dependent on the portion of the total sky hemisphere which is unimpeded by mountains and other nearby relief. The effect of nearby relief blocking portions of the diffuse skylight can be considerable since the quantity of incoming diffuse illumination is upwards of 5 times as great for the near-horizon portions of the hemisphere as compared to near zenith portions (Fraser, 1975). Accurate modeling of the indirect skylight component alone would therefore require intense topographic analysis for each pixel and was considered to be infeasible.

The same is true for scattered light from nearby surfaces which might impinge upon any one pixel. The effective modeling of this component was likewise considered to be too complex.

Despite the complexities of calculating the precise indirect illumination component, it was apparent that an indirect illumination contribution to the entire study area should be included in a successful normalization process. It appeared reasonable to assume that the indirect illumination was uniform or nearly uniform, throughout the entire test area. If this were true, the total illumination for any one pixel could be expressed as being proportional to

$$\cos \quad = c$$

where c = *indirect illumination constant.*

<u>Determination of 'c' / The CV Test</u>

To measure the effectiveness of any 'normalization' process, the coefficient of variation (CV) value for the entire normalized data set can be compared with the CV value of the original raw data. In this respect, the CV is defined as

$$CV = \frac{\text{standard deviation}}{\text{mean}} \times 100$$

and represents the relative variation of all the values for a data set.

'c' values	COEFFICIENT OF VARIATION MSS 4	MSS 5	MSS 6	MSS 7
RAW DATA	20.5	37.6	13.8	15.5
.0	24.3	36.9	18.8	19.5
.1	22.6	36.4	16.4	17.3
.2	21.6	36.2	14.9	15.9
.3	20.9	38.1898	14.0	15.1
.4	20.6	36.1542	13.4	14.6
.5	20.3	36.1596	12.9	14.2
.6	20.1	36.1897	12.7	14.0
.7	19.998	36.2023	12.5	13.9
.8	19.850	36.3	12.3	13.8
.9	19.860	36.4	12.3	13.738
1.0	19.807	36.4	12.19245	13.712
1.1	19.788	36.4	12.18288	13.688
1.2	19.761	36.5	12.19001	13.696
1.4	19.737	36.6	12.16420	13.7
1.6	19.747	36.6	12.22584	13.8
1.8	19.713	36.6	12.3	13.9
2.0	19.769	36.7	12.3	13.9
2.5	19.860	36.8	12.4	14.1
3.0	19.878	36.9	12.6	14.2
3.5	19.987	37.0	12.7	14.3

Table 1. Coefficient of Variation values for normalized 1% sample data sets with variable 'c' values. CV values of raw data are shown in top column.

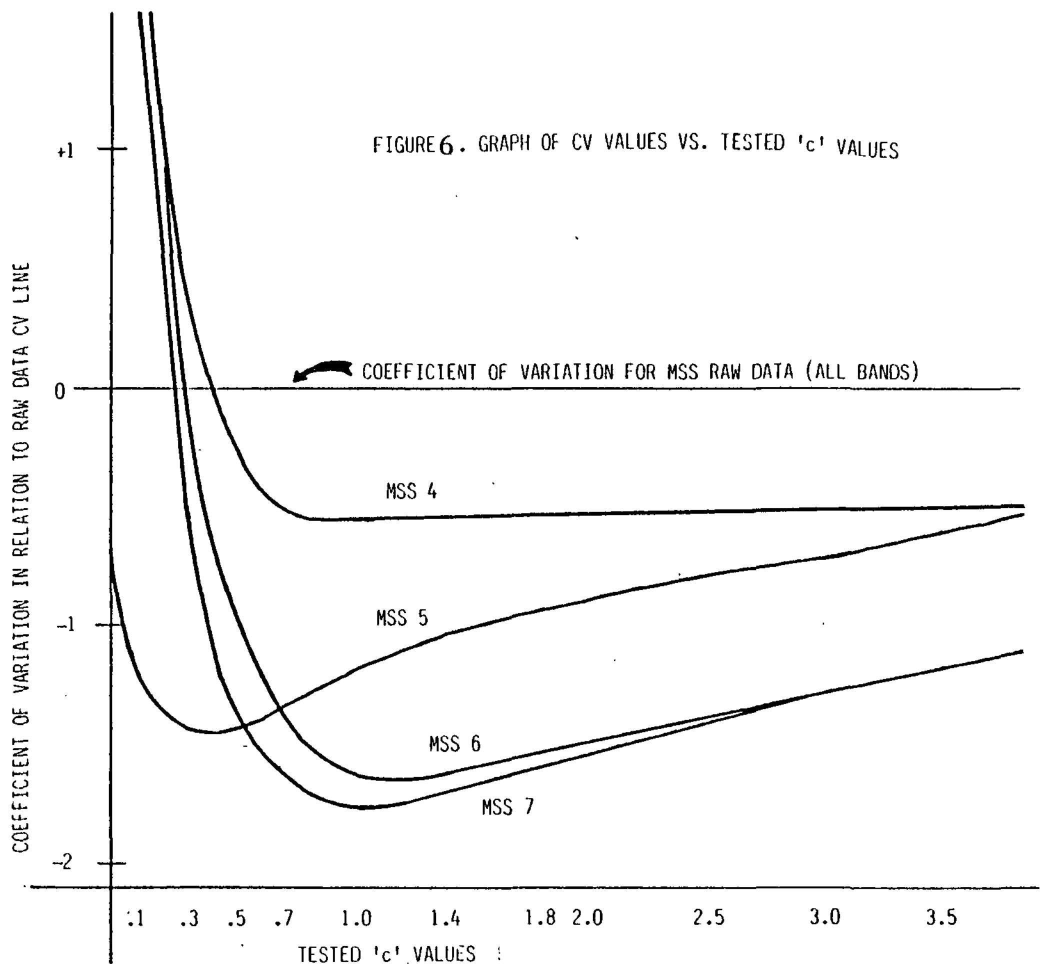

FIGURE 6. GRAPH OF CV VALUES VS. TESTED 'c' VALUES

As can be seen in Figure 2, as the 'c' value increases from zero the CV value drops dramatically for all four bands. As would be expected, the resulting curves reach a minimum and then begin a slow ascent which approaches the CV value of the raw data as c.

Another noteworthy aspect of the CV test is the simultaneous verification of the normalization process itself. As the direct solar component is tempered by increasing values of 'c' the variability introduced by the terrain is effectively removed and the relative variability of the data set (or CV) is reduced below the CV of the raw data bands.

Normalization

Assuming the 1% sample was representative of the entire raw data set, the 'c' value with the lowest corresponding CV was selected for the final normalization operation. By applying

$$P'_{ij} = \frac{P_{ij}}{\cos\theta + c_j}$$

where c_j = constant determined for band j having the lowest CV value for the 1% sample tests, a 'normalized' data set for the entire area was created. Figure 7 diagrams the processes leading to the final normalized bands.

Evaluation of Normalization Procedure

Black and white renditions of the raw data set and the 'normalized' data set can be compared by viewing Figure 5. Further, evaluation of the topography for the same area can be made by comparing these renditions with the direct solar illumination image shown.

In Figure 8 an area densely populated with conifer (Douglas fir) of variable age and density can be seen in the SW quadrant for both images. For this relatively homogeneous area the variability introduced by direct solar illumination at the time of Landsat MSS image acquisition is readily apparent.

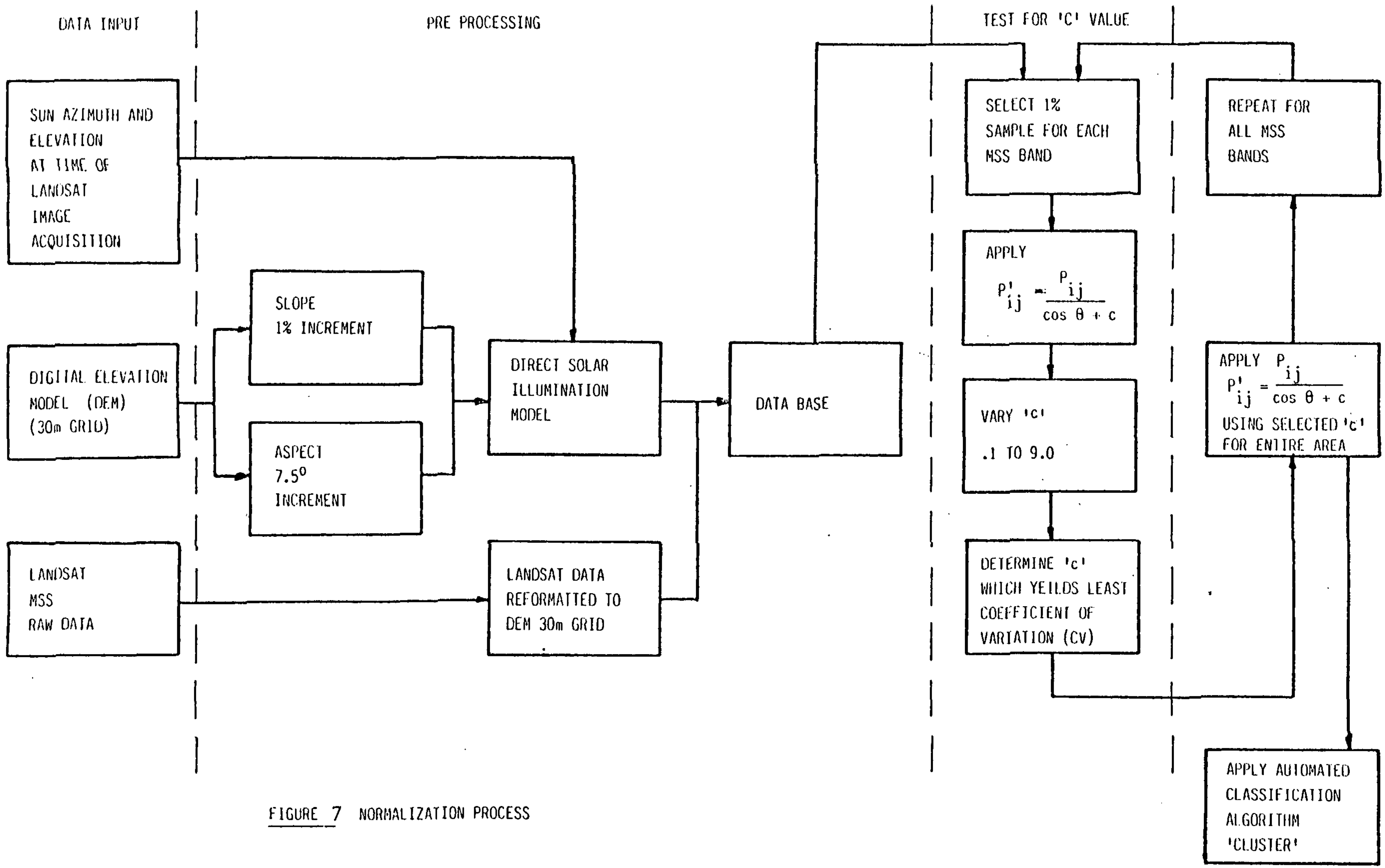

FIGURE 7 NORMALIZATION PROCESS

Raw Data (bands 4,5,7)

Normalized Stat (bands 4,5,7)

Figure 8. Comparison of MSS raw data vs. 'Normalized' data.

Likewise, the effects of the normalization procedure are apparent in the normalized image to the right of figure 8. The same change can be seen in the extreme NE corner of both images. In this area a hardwood complex occupies both west and east facing slopes. Areas which have little or no relief (e.g. the valley areas in the center and extreme SE corner) show no change in relative spectral value.

Figure 9 graphs the relative change in MSS 7 spectral values along a 25 pixel transect after the application of the normalization procedure. In this figure the relative values of the solar illumination band are also shown. As can be seen, the change is minimal for areas of little or no relief. The spectral values for areas in steep terrain are changed in proportion to their relative direct solar illumination values.

2.4.1. Preliminary Unsupervised Classification

A preliminary unsupervised classification of the normalized data set has been performed using CLUSTER (from Isoclas) at the RSRP DIANA (Digital Image Analysis) interactive graphics system. A simplified vegetation map derived from the resulting data set is shown in figure 10. Initial evaluations indicate that an improved classification with fewer iterations and fewer final classes (before re-numbering) may be possible using the 'normalization' procedure as a pre-classification process.

2.5.0 Conclusion

A method for reducing the spectral variability of Landsat MSS data caused by variable solar illumination in mountainous terrain has been demonstrated. A relatively easy and fast technique for determining the indirect solar illumination component of total illumination has also been shown. Both techniques are dependent upon accurate digital terrain models, the formation of a registered data base (including Landsat raw data, slope, and aspect) and knowledge of the position of the sun at the

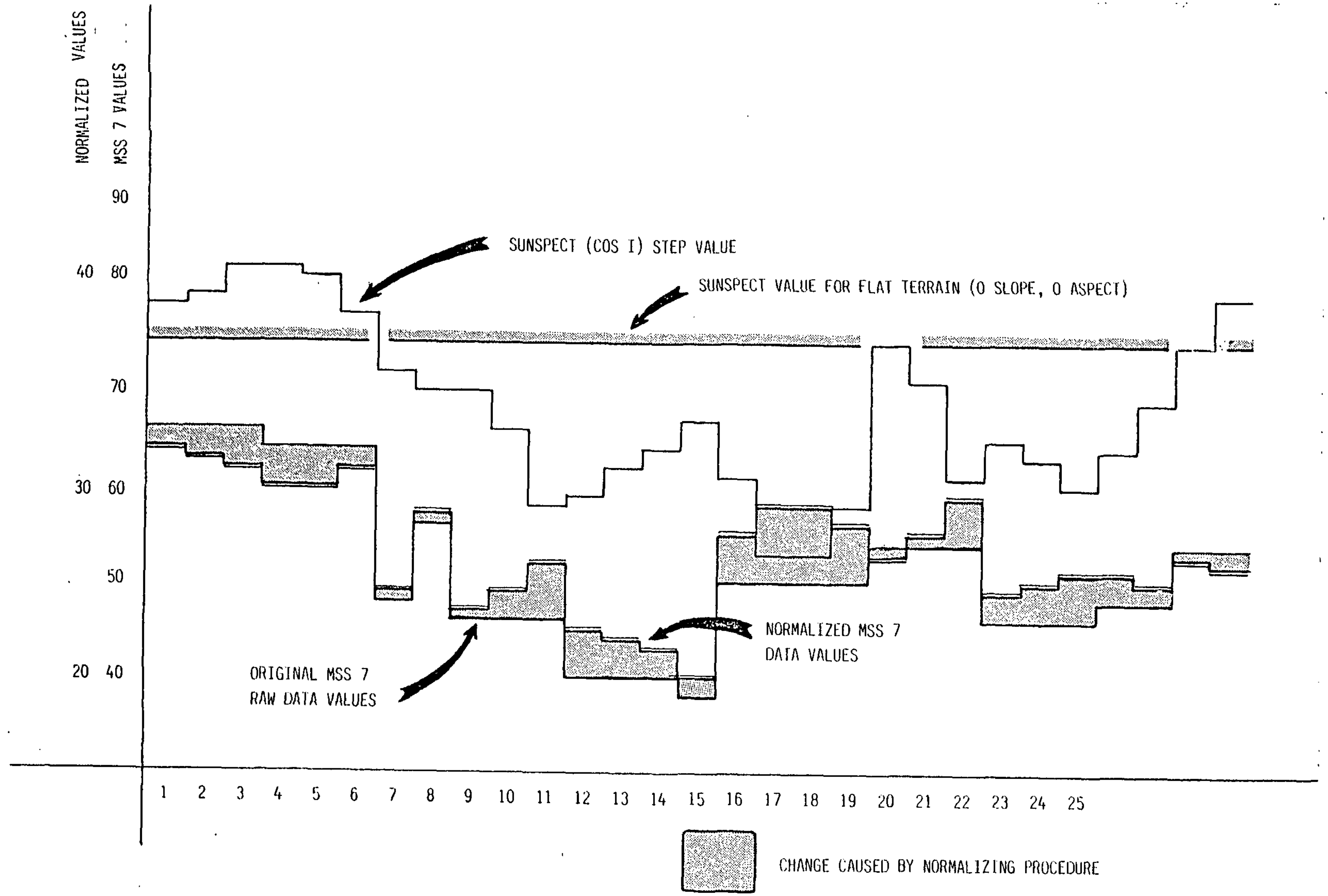

Figure 9. MSS7, Normalized MSS7, amd SUNSPECT values along a 25 pixel transect (West-East) are graphed.

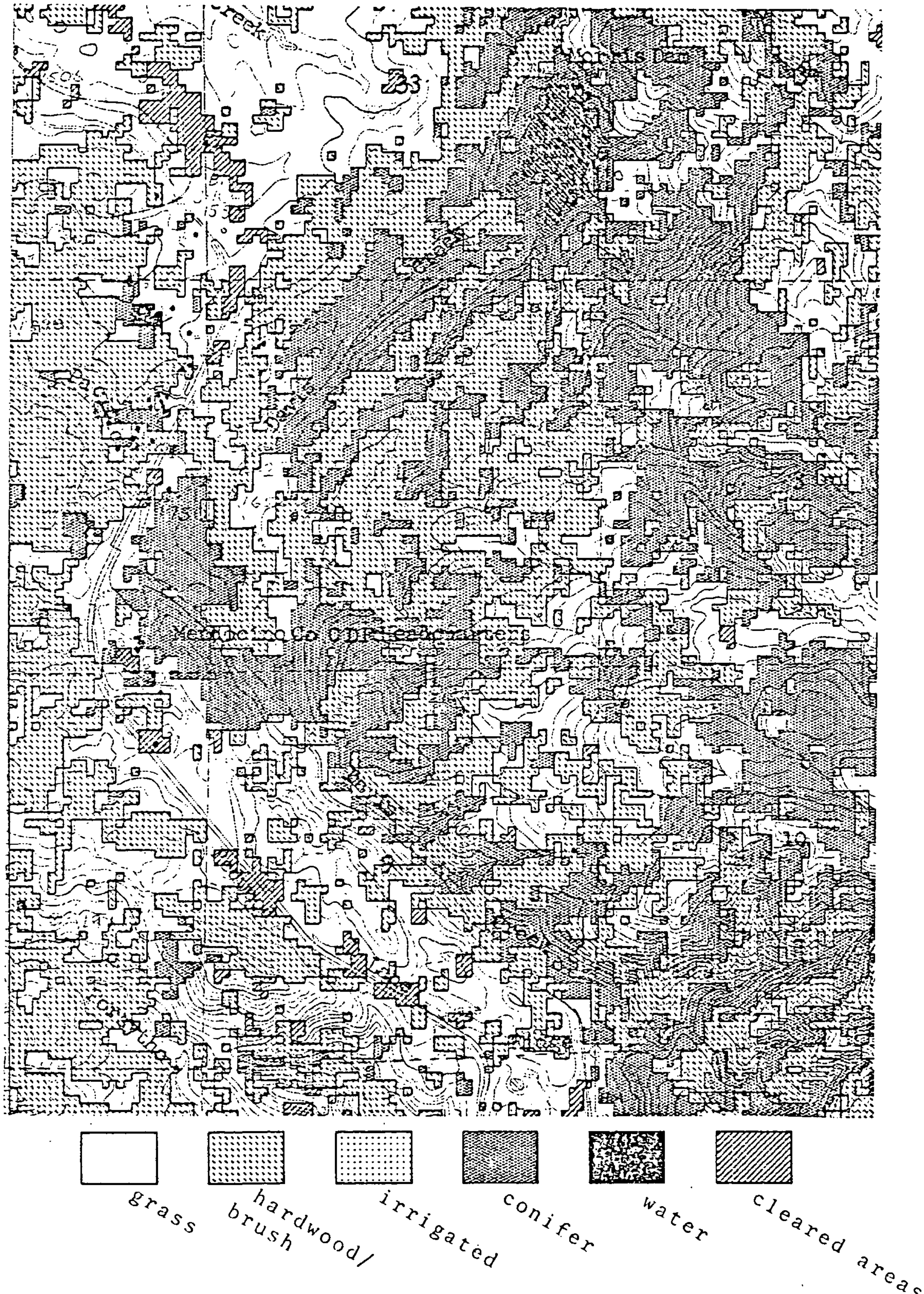

Figure 10. Simplified vegetation map derived from normalized Landsat data. USGS 7½' advance map is registered and overlayed. This map is an example of the final output recommended for Mendocino County's manual data base.

Scale 1:24,000 1"=2000'

time of Landsat image acquisition.

The applicability of this approach to the classification of Landsat MSS data in a variety of mountainous areas can only be determined by further testing and evaluations. It is suggested that such investigations be undertaken in a research project where a substantial large-scale interpretation and ground data collection capability can support the quantitative evaluation of the normalization procedure.

3.0.0 Evaluation of the Slope Component of Soil Descriptions in Mendocino County

3.1.0 Introduction

Soils maps and inventories include descriptions (attributes) which define the soil. Two major attributes contained in these descriptions are the slope and aspect values. Slope and aspect values indicate the drainage, erosion, hazard, weathering, and a number of other significant soil properties. Slope data is especially vital to the users of soils maps, for it is upon the slope data that the suitability and capability of the soil are determined.

In most instances the slope and aspect values associated with a soil or mapping unit are determined by spot field checks and estimates made from map measurements. With the availability of digital terrain models (e.g., digital elevation models - DEM - see section 2.2.0), systematic and comprehensive slope and aspect values can be determined for each soil.

In this investigation the slope values (as determined by the adjacent pixel - best-fitting plant algorithm, see section 2.4.0) were compared with standard field measurements as reported in the soil descriptions.

3.2.0 Background

The Soil Conservations Service (USDA) is the federal agency responsible for the inventory of soils and mensuration of soils capabilities throughout the United States. Classification is determined by scientific teams operating in rotation throughout state or multi-state regions. These inventories are performed at various orders of detail depending on the potential productivity of the soil (i.e., agricultural soils are generally mapped in greater detail).

For wildland areas a third order survey is generally performed. The level of detail and number of ground samples which support a third order survey reflect the lowest level soil survey (first order being the highest). A third order survey is currently in progress for all participating conservation district lands in Mendocino County. Using aerial photography (U-2 B&W and color IR) polygons depicting vegetation complexes with spectral and textural similarity are plotted. Soil scientists then take samples of the soil and define the soil types which are found in each polygonal area.

Each polygon (although appearing uniform on aerial photography) is very often a conglomerate or aggregate of several distinctly divergent soil types (soil series). Based on the samples, a relative percentage of each present soil series is attached to each polygon. Typically there are from one to three primary soils series in one polygonal area and often several other soils, called inclusions, which make up as much as 20% of the remaining polygonal area.

Where polygons have the same constituent soils series, they are defined as belonging to the same mapping unit. Each mapping unit is therefore a group of mapped polygons for which the constituent soils and their relative percentages are treated as being identical.

3.3.0 Slope and Aspect Test

Slope and aspect attributes are generalized for each soil and generally are the same for each mapping unit. A typical description includes a general slope description. For example:

"Bearwallow-Hellman complex, 15 to 30 percent slopes."

This slope value is estimated for each mapping unit based on ground samples and the soils scientists' familiarity with the area.

The task of this investigation was to compare the slope estimates from the SCS soils survey with slope values derived from digital elevation models.

3.4.0 Methodology

The data base prepared as part of the Forsythe experiment included the SCS soils series map (interpolated to a 30m pixel grid file) and a digital elevation model (also interpolated to a 30m pixel grid file). These two overlays were registered to one another using a standard linear coordinate transform with under $\pm$ 1.0 pixel position errors throughout the mapped area.

Using the DIANA (Digital Image Analysis) interactive graphics system at RSRP, each mapping unit in the soils overlay was isolated by masking out all but the specific soil in question. The mask then isolated the slope values for each singular mapping unit and a histogram of the slope values was generated for analysis. The histograms then were compared with SCS slope estimates.

Figures 11-15 show the resulting histograms and comparisons with SCs slope estimates for five soils in the Willits SE quadrangle.

3.5.0 Conclusions and Recommendations

Although the results of this comparison are preliminary, there is

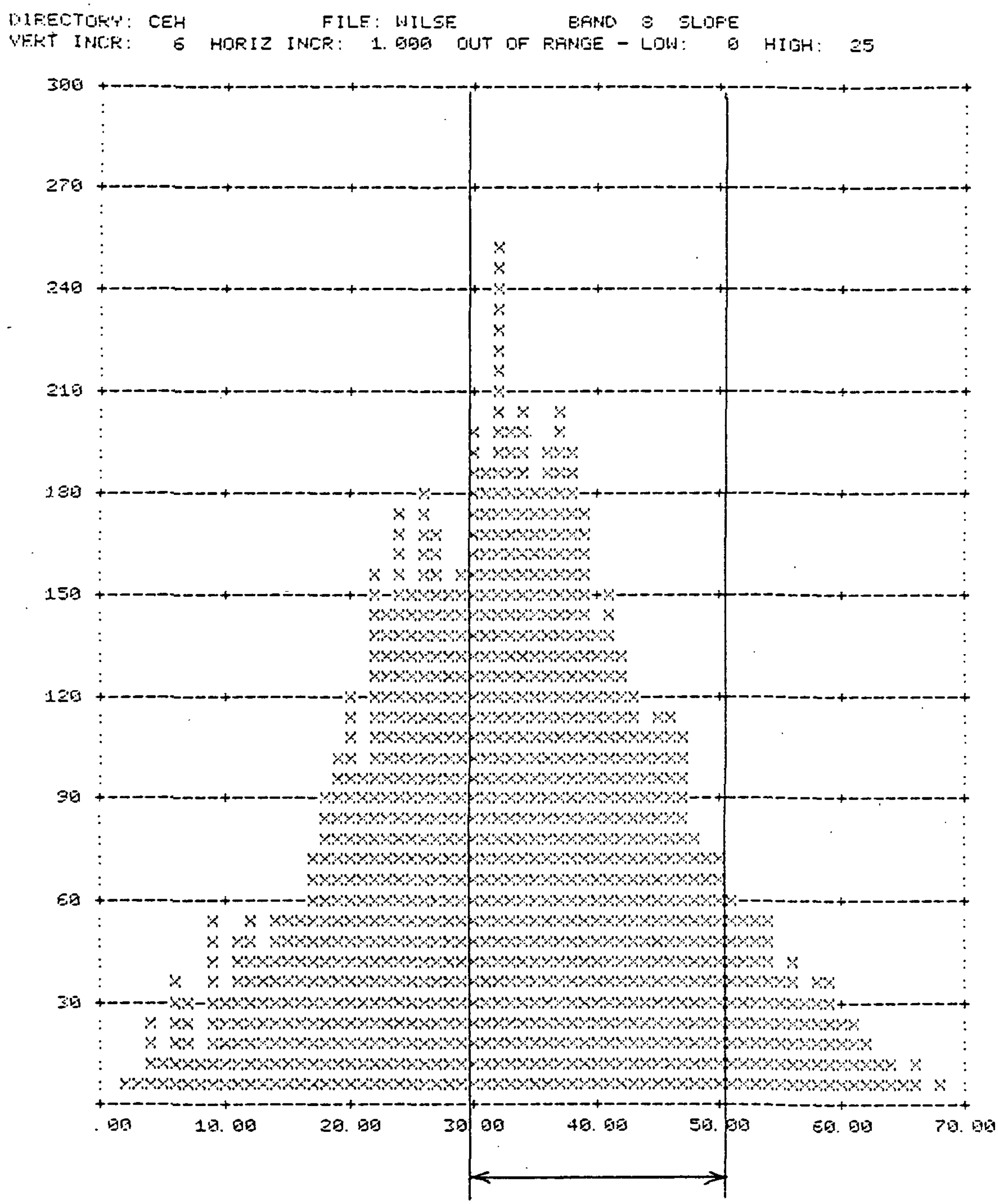

Figure 11. Yorktree-Hopland-Squawrock Complex

SCS estimated slopes 30-50%
DEM measured slopes (±SD) 20-45%

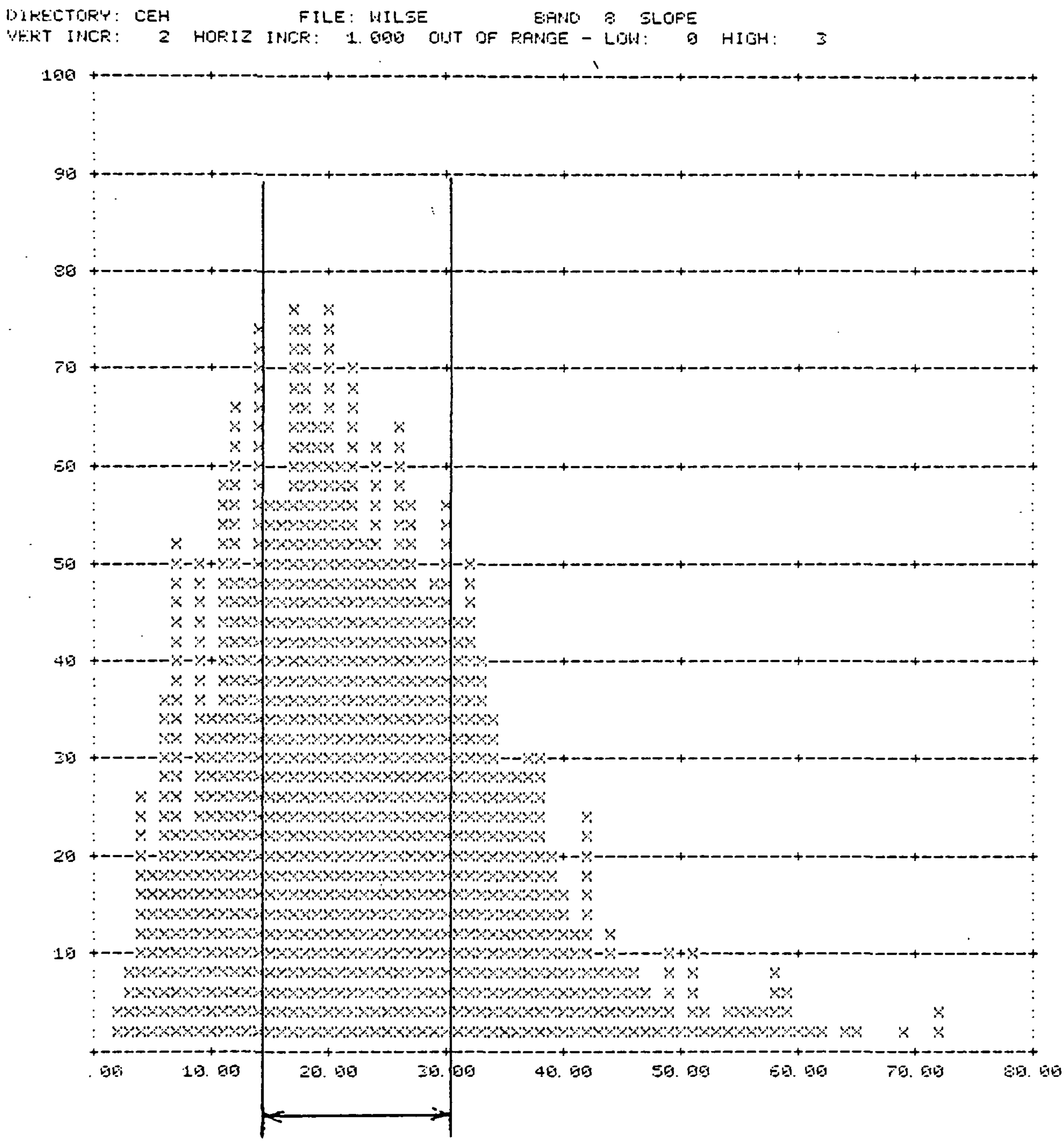

Figure 12. Bearwallow-Hellman Complex

SCS estimated slopes 15-30%
DEM measured slopes (±SD) 11-36%

VERT INCR: 8 HORIZ INCR: 1.000 OUT OF RANGE - LOW: 0 HIGH: 19

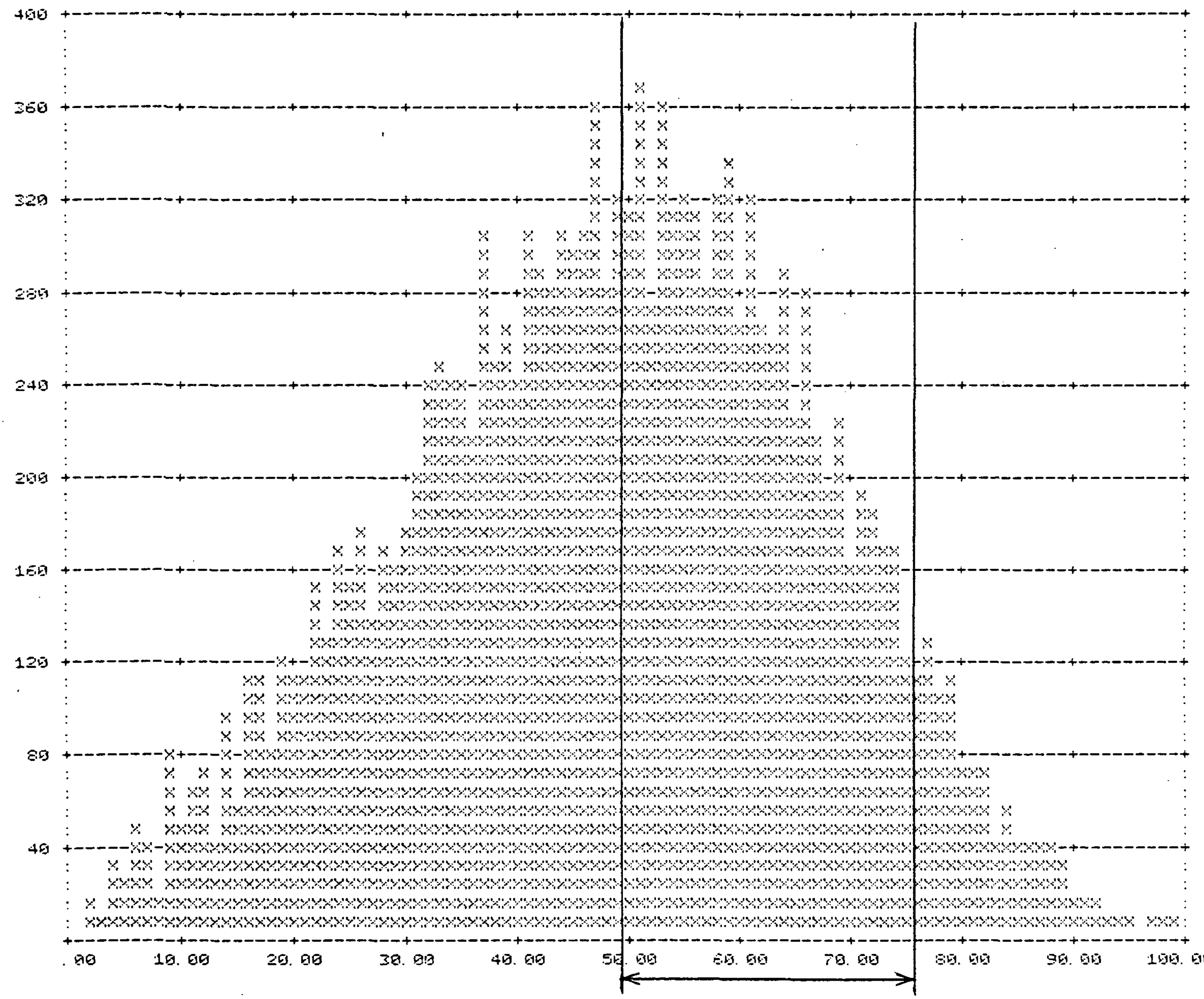

Figure 13. Yellowhound-Woodin Complex

SCS estimated slopes 50-75%
DEM measured slopes (±SD) 30-67%

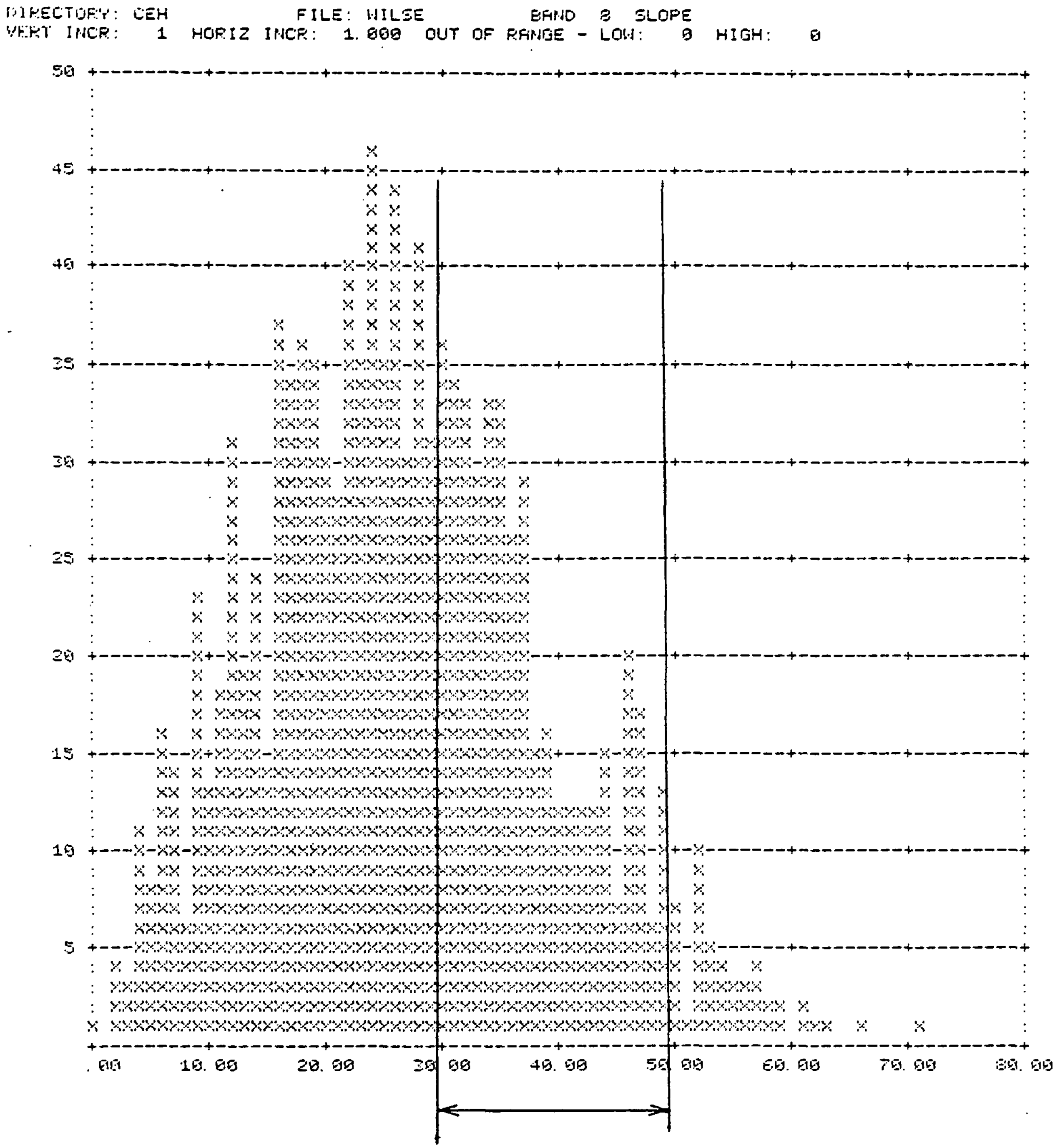

Figure 14. Shortyork-Yorkville-Witherall Complex

SCS estimated slopes 30-50%
DEM measured slopes (± SD) 15-39%

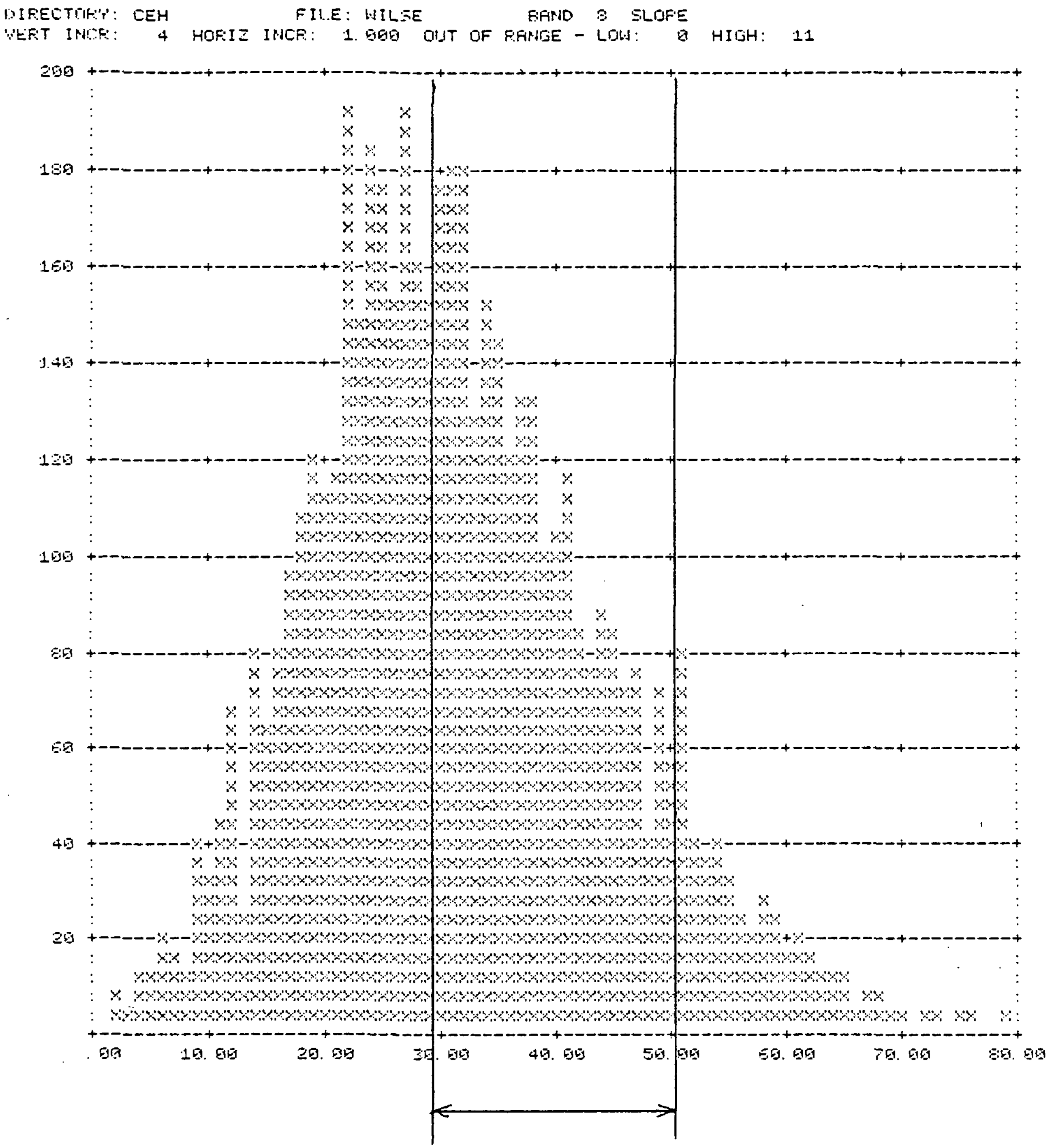

Figure 15. Bearwallow-Hellman-Witherall Complex

SCS estimated slopes 30-50%
DEM measured slopes (± SD) 19-46%

a significant discrepancy between the two methods of calculation. Most urgently needed is a careful ground sample measurement program to verify one or neither of the methodologies. Spot measurements on USGS topographic maps indicate a high degree of accuracy for the DEM-derived slope values. Overall, it is highly unlikely that the DEM slope values vary significantly from actual ground values since they are derived from known control points with verified elevations.

If the DEM-derived slope values for each soils mapping unit are found to be accurate, a significant reevaluation of the SCS soils data will be indicated. It is probable that DEM-derived products will play a major role in the preliminary mapping of soils and all subsequent classifications. Preliminary road engineering, development planning, reservoir design, pipeline suitability analysis, and a host of other uses of soils data would benefit from the new DEM slope data. Further, if the results of the DEM slope values are verified, it should not signal a grievous error on the part of past SCS efforts. Rather, it should indicate a new potential for soils survey accuracy and usefulness.

A ground check will be performed during the final phase of the Forsythe project. Tabulations and a final analysis will be included in the final report.

4.0.0 Data Base Development

The foundation task of the Forsythe Experiment has been the development of a computer-based geographic information data base. Attention has been given to prototyping a system for the Willits SE quadrangle and building a data base that could (1) meet the primary information needs of major county agencies and (2) provide this information at a reasonable cost.

Three primary information needs were isolated:

Vegetation/Ground Cover - the isolation of current land use, vegetation and ground cover types;

Soils Data - the availability of soils information covering a wide variety of attributes;

Terrain Models - the availability of slope, aspect, elevation, watershed boundary, drainage network, solar illumination, and other models developed from topographic data.

In addition, network data (i.e., roads, section boundaries, and 1000m UTM grid, etc.) were found to be of general importance.

Figure 16 outlines the various elements included in the final data base. Now that it is in place, this information is inexpensively accessible at any scale to any agency.

To develop a data base of this calibre for the entire county would be a significant investment. Table 2 estimates the costs which can be anticipated to develop a similar data base for additional $7\frac{1}{2}'$ quadrangles at the $30m^2$ resolution level. These estimates have been made using 1981 commercial computer vendor prices. However, it is reasonable to assume that these prices will remain reasonably consistent.

Total cost, for developing a comparative data base for every quad covering Mendocino, approaches \$240,000.00. This assumes a unit cost of \$3,179.00, where a unit is defined as

An expenditure of a quarter million dollars for a county-wide data base must be carefully weighed against the benefits of readily available resource data. Further, the costs of such a data base should not be borne by any one resource agency, since a great many agencies can benefit from the same data.

Table 2. Estimated Costs for 7½' Quadrangle Data Base

The costs involved in the generation of a data base for each 7½' minute quad are listed below. These costs were estimated based on the Willits WE quadrangle and apply more accurately where urbanization is not considered in detail.

SCS Soils Data

12 hours initial digitizing @ $20/hr		$240.00
Construction of raster file @ $80/hr		80.00
Erosion Hazard		6.50
Soil Depth		6.50
Available Water Capacity		6.50
Permeability		6.50
Prime Use		6.50
Effective Rooting Depth		6.50
	Subtotal	359.00

Digital Elevation Model (DEM) from USGS

Initial 30m Grid Model (this cost assumes a cost sharing agreement with USGS)		$1000.00
Slope and Aspect Model		50.00
Solar Illumination Model		25.00
Viewshed Models (per model)		35.00
		1110.00

Vegetation Models (Landsat satellite)

Vegetation Classification (wildland)		737.00
Fire Hazard Danger Rating 1		150.00
	Subtotal	887.00

Drafting of Land Net

Section Lines		20.00
UTM 1000m Grid		10.00
	Subtotal	30.00

Drafting of Network Data

Roads (approximate and wildland only)		30.00
Drainage		200.00
Powerlines		10.00
Pipelines		3.00
	Subtotal	243.00

Table 2. (continued)

Drafting of Watershed Boundaries	100.00
Drafting of Archaeological Data	150.00
Drafting of Property Boundaries	
(assumes property boundary maps, a 1:24,000 has already been prepared by the county assessor)	300.00
TOTAL COST	$3179.00

If the county-wide data base were developed over a five-year period, and if the project were supported by five agencies (e.g., County Planning, California Department of Forestry, U.S. Forest Service, Bureau of Land Management, County Public Works, County Assessor, State Department of Water Resources, etc.), the total cost/year/agency would be less than $10,000.00. These per-agency costs could, of course, be reduced even more if other agencies were to contribute. It is felt that only through an integrated and inter-agency approach, as described above, can a data base become affordable and successfully developed.

It will be recommended to the Mendocino County Supervisors that a geographic information system (GIS) be established. The GIS would include the development of the data base described above. Such a system should incorporate the participation of all major users of geographic information within the county and become the common clearinghouse for all geographic information. The initial step toward a GIS should be the vigorous reinstitution of the County Mapping Committee (first established in 1978). This group should take a lead role in coordinating GIS formation, major data development tasks, and subsequent mapping in Mendocino County. This committee should be comprised of representatives from state, federal, and county agencies who develop and/or utilize geographic data. The committee should have decision-making authority as to the sequence in which quadrangle data bases are developed and the dispersal of funds for this purpose.

It will also be recommended that any GIS which becomes operative within the county utilize existing computer facilities in the region and a telecommunications network to access and manipulate the data base.

Under this plan, the county will avoid the overhead and front-end costs of additional computer acquisition and will be able to utilize software packages which reside within a number of service vendor systems. The key to a successful, functioning GIS will be maximizing the flexibility and adaptability of the data base to a variety of computer systems (i.e., if BLM is to participate, the data base will need to be compatible with the GIS hardware and software packages this agency is currently implementing). By taking advantage of the proximity of the San Francisco Bay area computer industry, Mendocino County can inexpensively communicate with vendors, request maps, perform suitability analyses, and interactively edit and update the data base. It will also be recommended that a GIS be established which is driven by telecommunication ports to remote systems, and a cost estimate for total system implementation will be prepared. For the initial phases of GIS development, digitizing chores, plotting, and other I/O activities can be subcontracted also. As the system expands, the committee will perhaps recommend purchase or lease of plotters, digitizers and other peripherals. A final report outlining GIS options for Mendocino County will be prepared as a portion of this project and delivered to the Mendocino County Board of Supervisors by the end of summer, 1981.

The following maps are greatly reduced renditions of the computer-generated map products being prepared for inclusion in the Planning Department manual data base. Final plots of each map will be overlayed with a controlled base map for accurate ground location. Figure 10 is an example of such a combined product.

Figure 16. Data layers in Forsythe Experiment data base ($30m^2$ grid)

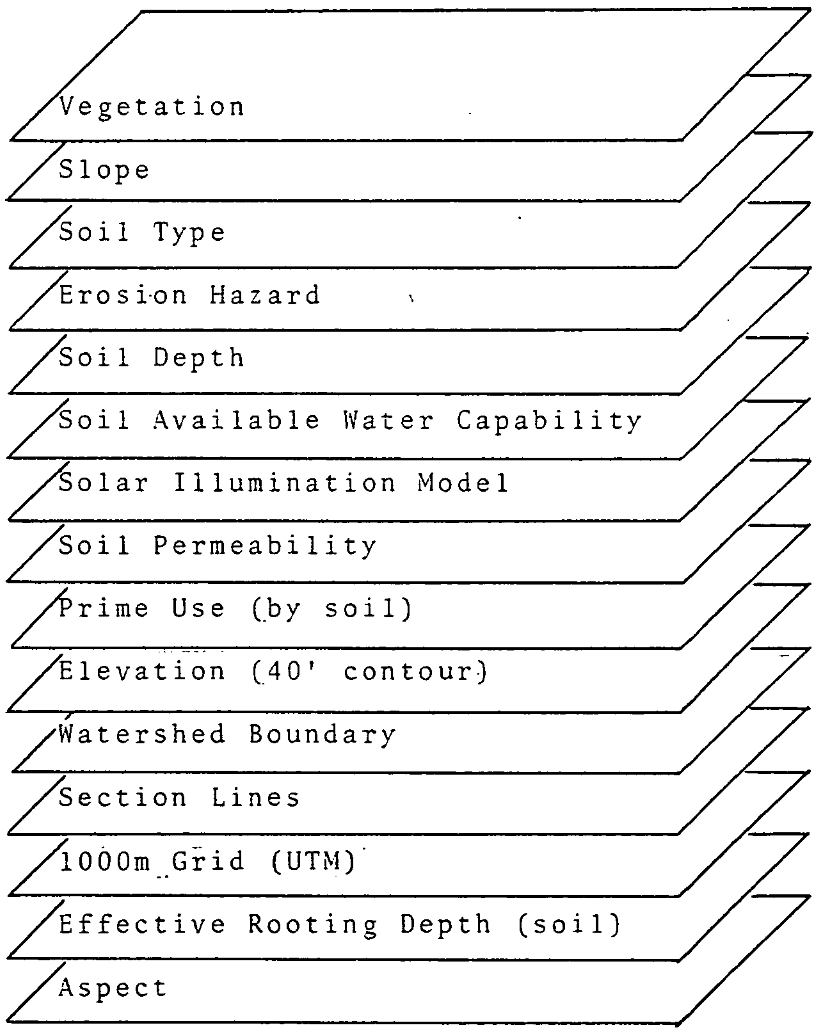

Figure 17. Aspect Values derived from digital elevation model (DEM). Approximate scale = 1:58,000 or 1" = .9 miles

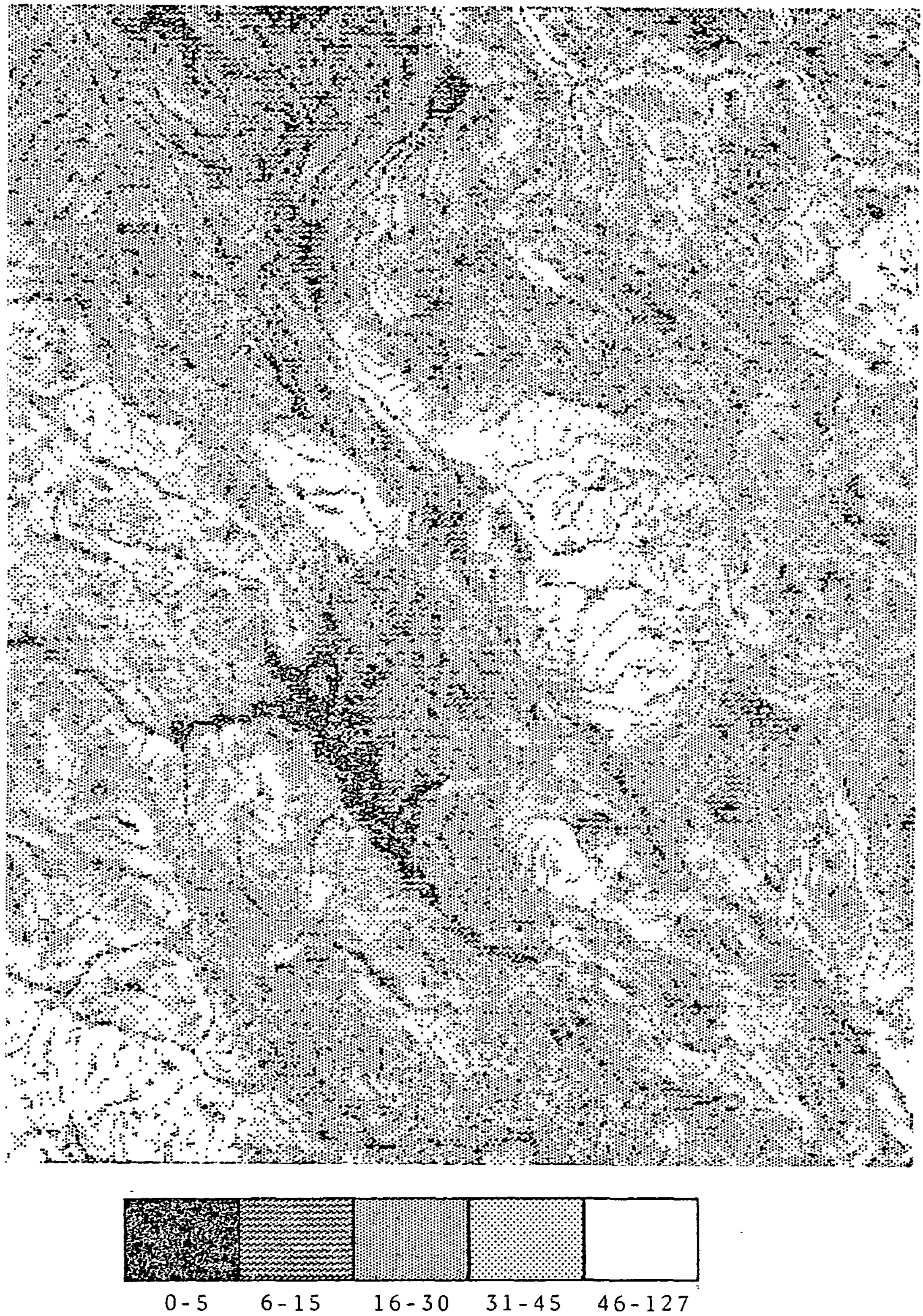

Figure 18. Slope Class Map developed from Digital Elevation Model.

Approximate scale = 1:58,000 or 1" = .9 miles

Figure 19. Rooting Depth from SCS soils data

Approximate scale = 1:58,000 or 1" = .9 miles

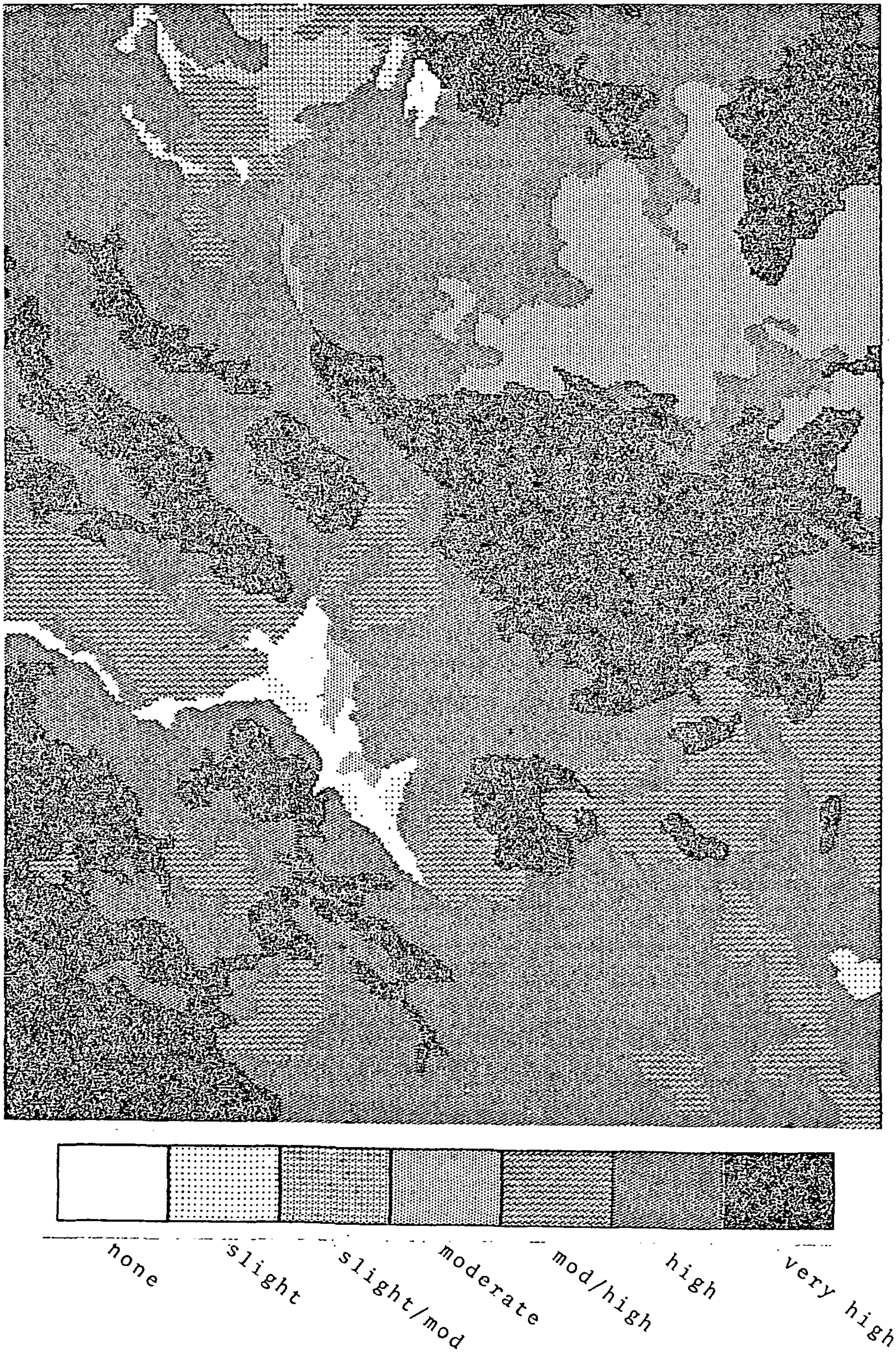

Figure 20. Hazard of Water Erosion, from SCS soils data

Approximate scale = 1:58,000 or 1" = .9 miles

5.0.0 Follow-on Work/Project Completion

The Forsythe Experiment is nearly completed. Remaining tasks include the preparation and delivery of a final report to the Mendocino County Board of Supervisors, the Planning Commission, and a variety of other interested groups. A final report will also be prepared and included in next year's annual report. In addition, the final maps and suitability models described in the annual report (1 May 1981) will be completed and final maps generated.

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PART III

DEVELOPMENT AND EVALUATION OF A DIGITAL SPECTRAL/TERRAIN DATA SET FOR COORDINATED RESOURCE PLANNING IN COLUSA COUNTY, CALIFORNIA

by

Louisa H. Beck

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PART III

DEVELOPMENT AND EVALUATION OF A DIGITAL SPECTRAL/TERRAIN DATA SET FOR COORDINATED RESOURCE PLANNING IN COLUSA COUNTY, CALIFORNIA

1.0 Introduction

1.1 Historic Background

Coordinated Resource Planning* is a process by which the cooperative efforts of land owners and public agencies improve the management of the land and its resources in a given area. This approach to land management has many positive aspects:

1. Cooperative planning avoids duplicative and/or conflicting actions between neighboring land owners, and provides far more comprehensive and efficient management.
2. This comprehensive approach reduces the chance of overlooking potential multiple use benefits.
3. The cooperative nature of the process provides for private as well as public agency input into land management actions, making this type of planning a participatory and educational process.
4. Building upon (3), the interchange between public agencies and the private owners provides a base of understanding, so that the agencies are cognizant of the owners' needs, while the landowners may come to understand why some seemingly valuable ideas cannot be implemented.

The process itself exploits the knowledge and expertise special to each of the concerned participants. The participants, as a committee, inventory the area of mutual concern, analyze the data, identify and agree upon common management objectives, and then evaluate and select among the various alternatives in order to achieve those objectives. Through this approach, the committee structures its management alternatives in accordance

*Coordinated Resource Planning is the term applied to certain cooperative efforts of land owners and public agencies in order to improve the management of the land and its resources in a given geographic area. This type of planning is mandated by the 1975 Memorandum of Understanding (see Appendix A).

with both the resource base itself and the mutual objectives of the group. It also takes into account the dynamic nature of the land resource, as the committee meets on a regular basis in order to monitor all actions and to amend any portion of the coordinated resource plan.

Coordinated Resource Planning, therefore, is a mechanism by which the goals of private land owners and public agencies can be combined in order to provide more efficient and responsive management schemes, which will maximize multiple use benefits with limited monetary funds. It also ensures that no single agency is responsible for all land use planning efforts.

In order for Coordinated Resource Planning to be successful, the planning committees must acquire and analyze timely inventory data, and evaluate the impact and cost-effectiveness of each feasible management action in relation to proposed land use. Although management costs are shared between private owners and public agencies, the extensive data requirements still make it difficult for responsible groups to keep abreast of the dynamic changes in the environment.

In Colusa County, California, the Stonyford Resource Conservation District (RCD) has recognized that such changes are occurring. Specifically, large stands of decadent chamise have been encroaching on neighboring agricultural areas, resulting in reduction of rangeland and productive ecotone environments for wildlife. The increasing brush has also adversely affected water yield, and poses a considerable fire danger to both wildlife and cultural activities in the area.

In 1977, the Stonyford RCD initiated the Grapevine Coordinated Resource Plan. (See Figure 1 for the location of the Grapevine study area in Colusa County.) The purpose of the plan was to address the concerns expressed above. The agencies involved included the California Department of Forestry (CDF), California Department of Fish and Game (CDF&G), USDA Soil Conservation Service (SCS), USDA Forest Service, USDA Agricultural Stabilization and Conservation Service (ASCS), UC Cooperative Extension Service, and USDI Bureau of Land Management (BLM). Cooperating with these public agencies are 27 private land owners, the Colusa County Board of Supervisors, and the Indian Valley Fire Protection District.

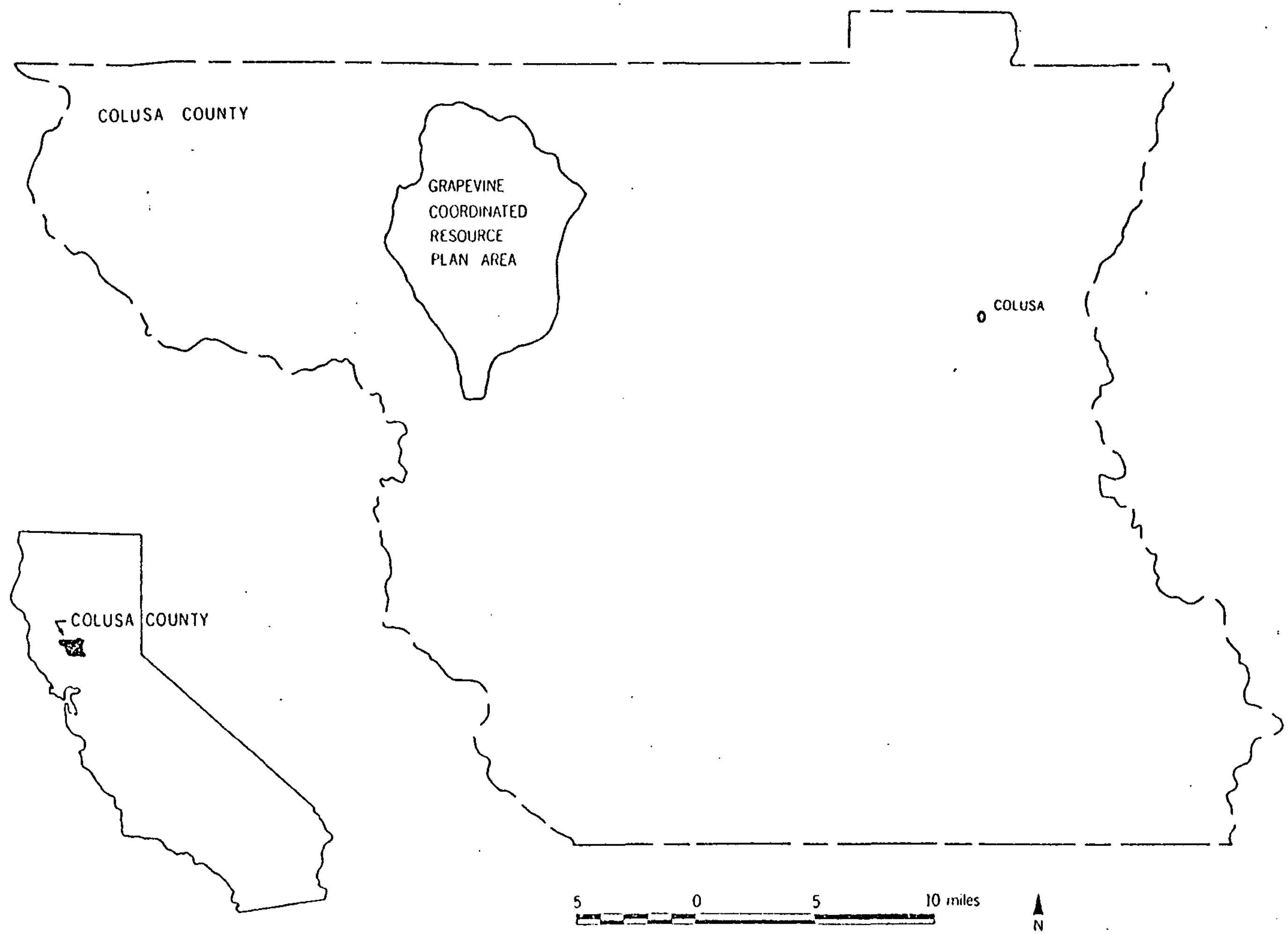

Figure 1. Location of the Grapevine study area in Colusa County, California.

Each participant's concern stems in part from the extensive and continuous stands of decadent chamise located along the western ridges of the Grapevine area. Although these brush stands represent many potential negative impacts for the area (e.g., lower water yield, reduced wildlife and domestic forage), the primary concern is that the continuous coverage of chamise represents an extreme fire hazard. The resulting loss of plant cover from a wildfire would create serious erosion problems on the upland soils, and eventually bring about serious sedimentation problems in the productive alluvial valleys below. This would have severe repercussions on both wildlife habitat and agricultural resources in the resource district.

To manage the Grapevine area and to achieve the RCD's planning goals, the RCD committee has had to collect extensive data on the areal extent of brush, as well as information concerning brush stand condition, soils, slope, and surrounding vegetation conditions. Unfortunately, the majority of the Grapevine area is roadless. Slopes in the area are generally steep and soils are susceptible to erosion and to damage from vehicular use. Yet some timely and cost-effective method for collecting data was needed so that the RCD committee could make specific management recommendations for the resource district. This method had to be comprehensive and provide for ongoing input, so that an accurate inventory base could be maintained.

Towards this end, the RCD committee has been considering the value of using remotely-sensed data to meet in part their information needs. The first demonstration of remote sensing applications in the Stonyford RCD came in June, 1978, when personnel from UC's Remote Sensing Research Program (RSRP) provided the personnel of the Colusa Field Office of the SCS with training in the use of high-flight* color infrared photography as a tool for resource inventory. Largely because of this training, SCS personnel were able to locate 100 new spring sites within the Grapevine area using this photography. The discovery of these spring sites has aided ranchers in the area by facilitating the location of cattle watering ponds.

*The term "high-flight" pertains to a flight altitude of approximately 65,000 feet above the terrain -- the altitude from which aerial photography is routinely taken by NASA's U-2 aircraft in support of projects such as the one dealt with in this report.

By use of this small-scale photography, SCS personnel were thus able to inexpensively and quickly locate a resource that would have taken many months of arduous field work.

The goals of the Grapevine Coordinated Resource Plan require much data that would be both expensive and laborious to collect in the field, as well as cumbersome to correlate and combine into a useful format for resource management applications. Added to the problems associated with developing a voluminous data base, the density and extent of the brush community makes field access for the collection of information needed for brush management nearly impossible.

The usual manual techniques for building a geographic information system involve digitizing (encoding) soils and vegetation data, along with other terrain attributes, from conventional photography and topographic maps. These data sources are often at different scales, which necessitate scale adjustments in order to create a series of thematic maps that overlay accurately. The digitization process is a tedious one, and requires special equipment. Once the soils and vegetation parameters are encoded, the user must also decide what type of topographic information is needed, and how best to integrate it with the other data. Manual calculation of slope is perhaps the most time-consuming process a user faces, although there are several methods by which slope can be derived. Unfortunately, some areas of the State, including the Grapevine area, do not have the 7½-minute topographic coverage needed for slope determination at a useful scale; the alternative is to use 15-minute topographic maps for slope derivation.

Because of the quantity of data needed and the impenetrable nature of the brush fields, certain members of the RCD committee felt that an inventory system that employs remotely-sensed data would help meet their information needs. This type of data helps alleviate the tedious process of digitizing vegetation and terrain information from photography and topographic sheets, and the digital format makes resource data easier to store, reference, analyze, and manipulate. The SCS personnel arranged with UC Berkeley's RSRP for assistance in developing a Landsat-based data set for the Grapevine area. Digital Landsat data were chosen because, when used in conjunction with other forms of ancillary data (e.g., digital terrain data), they provide a solid data set with which to achieve the RCD's objectives.

In 1979, personnel from the RSRP demonstrated that the application of remote sensing-derived information, and its associated technology, could provide a cost-effective means for inventorying and analyzing large areas for resource planning in Mendocino County, California (Benson and Beck, 1979). Although that study was conducted for a much larger area, some of the goals of the RCD plan could be realized in the 43,000-acre site using Landsat-derived data and technology, with appropriate modifications.

Initial funding for this work was provided through a program of the California Space Institute ("Calspace") in order to evaluate and apply remote sensing-derived information to Coordinated Resource Planning in Colusa County, California. The result of this study was evaluation of two basic spectral and terrain data sets already in existence and currently available to Coordinated Resource Planning groups throughout California. As research in this area is of ongoing concern throughout the State, additional funding has been granted for pursuit of this work under NASA Grant NSG 7220, NASA Office of Space and Terrestrial Applications, through its University Applications Program.

1.2 Objectives

The objectives of this project were fourfold. Our primary goal was to acquaint the Stonyford RCD committee with the applications that might be made of existing digital satellite-derived spectral data and terrain data to the planning process. As the committee consists of representatives of various State and federal agencies, this small demonstration would expand the knowledge of remote sensing techniques and applications to other agencies.

The second objective was to investigate the applicability of California's statewide digitally-mosaicked Landsat data set for Coordinated Resource Planning in a relatively small wildland area. The statewide spectral data set used was developed in cooperation between the NASA-Ames Research Center, the Jet Propulsion Laboratory, and the California Department of Forestry, and is hereafter referred to as the CDF data set. As Coordinated Resource

Planning is generally limited to localized areas, we felt it necessary to investigate the usefulness of satellite-derived data systems for the smaller wildland area. This objective has application beyond Coordinated Resource Planning in that many federal and State agencies administer small holdings that are not currently considered amenable to spacecraft remote sensing applications.

The third objective was to develop a methodology whereby the general vegetation classes of the CDF data set could be refined to more pertinent classes for brush management purposes in Colusa County. This objective was based on the desire of SCS personnel to distinguish the more decadent stands of chamise from the younger and less flammable stands. If a correlation could be found between spectral characteristics and age class/stand condition, substantial advances in brush management throughout California's wildlands could occur.

The fourth objective was to promote use of the refined satellite-derived information, along with digital terrain information, by resource managers in Colusa County for formulating and implementing various resource management decisions of the RCD plan. Use of this type of data should assist in the efficient allocation of management resources. As areas of concern for fuel management are located by management personnel on the image products, both terrain and acreage information can be derived from the data set that would expedite management activities.

1.3 The Grapevine Coordinated Resource Plan Area

The Grapevine Coordinated Resource Plan Area is located twenty miles west of Colusa. It encompasses 43,000 acres of parallel ridges trending north-south (Figure 1). The upland areas are composed of tilted sedimentary formations; elevations in the study area range from 350' at the town of Sites, to approximately 2400' at Lodoga Peak. Soils are sedimentary in origin, and are generally shallow and erosive. Vegetation consists of pure stands of chamise *(Adenostoma fasciculatum)*, manzanita *(Arctostaphylos sp.)*, ceanothus *(Ceanothus sp.)*, buckeye *(Aesculus californicus)*, mountain mohogany *(Cercocarpus betuloides)*, and yerba santa *(Eriodictyon californicum)*, with digger pine *(Pinus sabiniana)* dispersed throughout the steep slopes, and blue oak *(Quercus Douglasii)*, valley oak *(Q. lobata)*, and live oak *(Q. Wislizenii)* in the woodland areas.

The Grapevine Coordinated Resource Plan (1979) lists the vegetative components, and their respective proportion of the study area, as follows:

annual grass/blue oak	13.0%
chamise	26.5%
blue oak woodland	39.0%
annual grassland	17.0%
mixed chaparral	4.0%
riparian woodland	0.5%

The current management goals of the Grapevine Resource Plan reflect the concern over the expanding coverage of decadent chamise in the area. There are basically two types of brush management techniques employed in areas of this kind throughout California: type conversion and fuel modification. Type conversion involves the complete removal of brush, followed by reseeding with varieties of grass or planting of trees. Thus, the area is not only converted to a more valuable resource in terms of wildlife habitat and/or commercial activities, but fire hazards are reduced substantially. This technique can take place only where soils and slopes permit long term conversion to grass or trees, as they cannot successfully compete with brush on poorer soils. A final consideration for type conversion is one of areal extent; generally speaking, areas of less than five acres are not considered economically feasible for this option.

Because the soils in the Grapevine area are often too thin or poor to support type conversion, fuel modification is the preferred management option for extensive brush fields. The modification objective in Colusa County is to establish a mosaic of age classes throughout the brush community, as each age class has a different fire response which reflects the ratio of live to dead material. Modification techniques include chaining, burning, crushing, or any combination of the three. Generally, the older, more decadent brush stands are identified, chained and crushed, and then burned. The chamise that sprouts in the burned area will resist burning due to its high proportion of live, green material and low density. By developing a scheme of planned rotational burns, a mixture of age classes can be maintained, thereby inhibiting the spread of fire. As a supplemental measure, fire breaks are constructed on kep ridges to keep fire outbreaks localized.

In order to develop a fuel modification scheme for the Grapevine aréa, information concerning age class and stand condition must be obtained. Due to the impenetrable nature of the brush fields, which are quite extensive, these data requirements have been difficult to obtain. The Colusa field personnel of the SCS have been employing aerial photography to determine the location and extent of the various age and stand conditions in the inaccessible portions of the study area.

1.4 The Existing Data Sources

To meet the objectives stated in 1.2, the CDF spectral data set was combined with the Defense Mapping Agency's digital terrain data set in order to build a Grapevine geographic information system; this new data set could be used by the RCD committee for management purposes. A data bank of this type could serve a multiplicity of purposes, as the combination of the digital spectral data with the digital terrain data would enable a user to determine a real extent of evgetation types as well as the topographic characteristics associated with them. The digital terrain information was also of interest due to the current lack of USGS $7\frac{1}{2}$-minute topographic coverage of the area. The land manager could therefore determine percent slope in areas of interest more readily and accurately than would be possible on the smaller scale 15-minute topographic map sheet. The data set would organize several layers of information more efficiently, and would be available for use on a real-time basis as well as for data bank applications.

Two data sets were chosen for the study: the CDF spectral data set and the digital terrain data set produced by the Defense Mapping Agency. They were selected because of their availability and relatively low cost. Both the CDF and terrain data sets are part of the public domain, and are currently being used to some extent by planning and resource agencies throughout the State. The costs associated with data acquisition are relatively low for these data sets because they have already been processed; therefore, those agencies purchasing data are essentially paying the cost of the magnetic tape to which the data are written.

1.4.1 The CDF Data Set

The primary Landsat data set that was used to meet the objectives of this project covered the CDF's 1° x 1° Ukiah East quadrangle (Figure 2). The quadrangle was part of the data set developed by NASA's Jet Propulsion Laboratory (JPL), Pasadena, California, and NASA-Ames Research Center, Moffett Field, California, for the California Department of Forestry (CDF). Using the VICARS system at JPL, August 1976 Landsat-1 MSS scenes covering the entire State were digitally mosaicked, resampled to produce 80-meter^2 picture elements, or pixels, and registered to a Lambert Conic Conformal projection (Newland, Peterson, and Norman, 1980).

The multiband spectral data set contained the four bands of transformed Landsat MSS data, with a fifth band of classified data. The four raw data bands consisted of the following: Band 1 -- VMSS* (green), Band 2 -- VMSS 2 (red), Band 3 -- VMSS 3 (near reflectance infrared), and Band 4 -- VMSS 4 (far reflectance infrared). The fifth band represented an unsupervised classification of the first four bands, i.e., a classification which resulted in the sorting of the pixels into natural groups based on their multiband spectral brightness values.

To simplify the classification task, the State had been divided into 32 ecozones, and the resulting CDF classification was based on the statistics generated from each ecozone. Each cluster was then labeled as one of the ground cover classes as defined by the field personnel from the CDF. (For a complete discussion of the CDF data set, see Benson and Beck, 1979, and Newland, *et al.*, 1980.)

The advantages of using this data set are its statewide availability and low cost. The classified portion would be of considerable value to those user agencies without access to an in-house computer system with classification capabilities.

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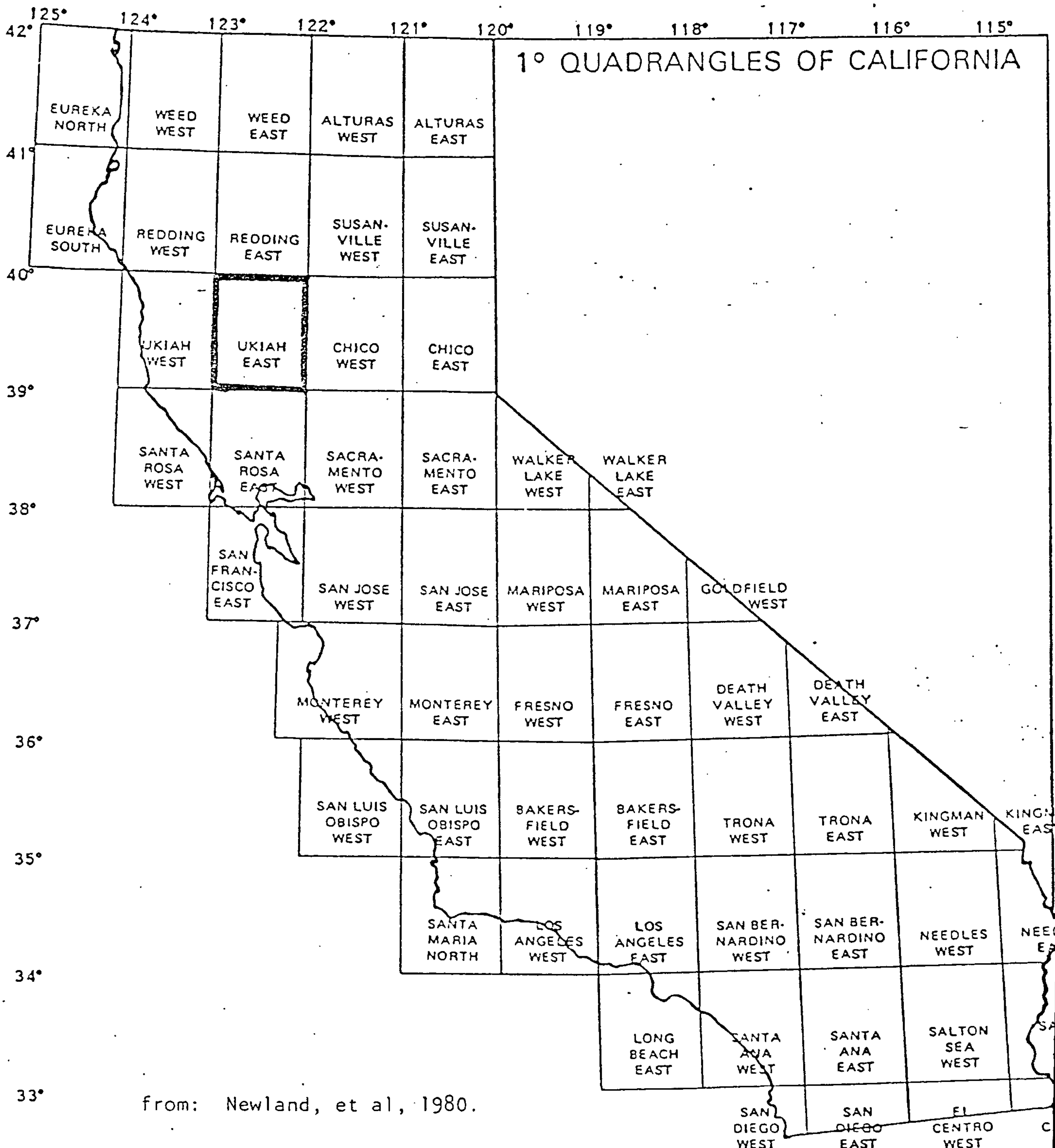
*VMSS refers to Landsat MSS data bands that have been reformatted using the VICARS software at JPL.



from: Newland, et al, 1980.

Figure 2. Arrangement of the 1° x 1° quadrangles which make up the CDF data set. The Ukiah East quadrangle, which contains the Grapevine study area, is outlined.

1.4.2 The Digital Terrain Data Set

The terrain data set used in this project was produced by the Defense Mapping Agency Topographic Center, and was made available in tape format from the National Cartographic Information Center. Digital terrain tapes (DTTs) have been produced for the entire United States, and were digitized off the USGS 1:250,000-scale topographic series maps. The data are in 1° x 2° quadrangle format, and consist of elevation values that have been digitized and interpolated to a 200-foot contour interval. Each pixel represents an area of approximately 63-meters^2. The terrain data for the Grapevine area were extracted from the Ukiah East DTT. As in the case of the spectral data, this form of terrain information was chosen because of its ready availability and low cost. Both of these factors are important considerations if this type of data base is to be utilized by the smaller RCDs throughout the State.

2.0 Processing Procedure

In order for the analyst (and thereafter, field personnel) to reference the spectral data and the terrain data sets to a ground coordinate system, registration of both data sets to a common geographic base was necessary. Figure 3 graphically represents the steps by which the data set registration was achieved. The ground coordinate system chosen was the UTM grid system, which is based on a 1000-meter square grid. The UTM system was selected because (a) it is represented as a system of squares on map sheets, and (b) it is found on most current USGS maps.*

Neither the spectral nor the topographic data sets could be directly related to a common map base without some form of coordinate transformation step. While the CDF data set had been mapped to a Lambert Conic Conformal projection, the digital terrain data had been mapped originally to a UTM projection. Both of these projections have their attendant degrees of dis-

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*Note: The UTM grid can, by appropriate dimensional correction, be overlain on any map projection. It should not be confused with the UTM projection.

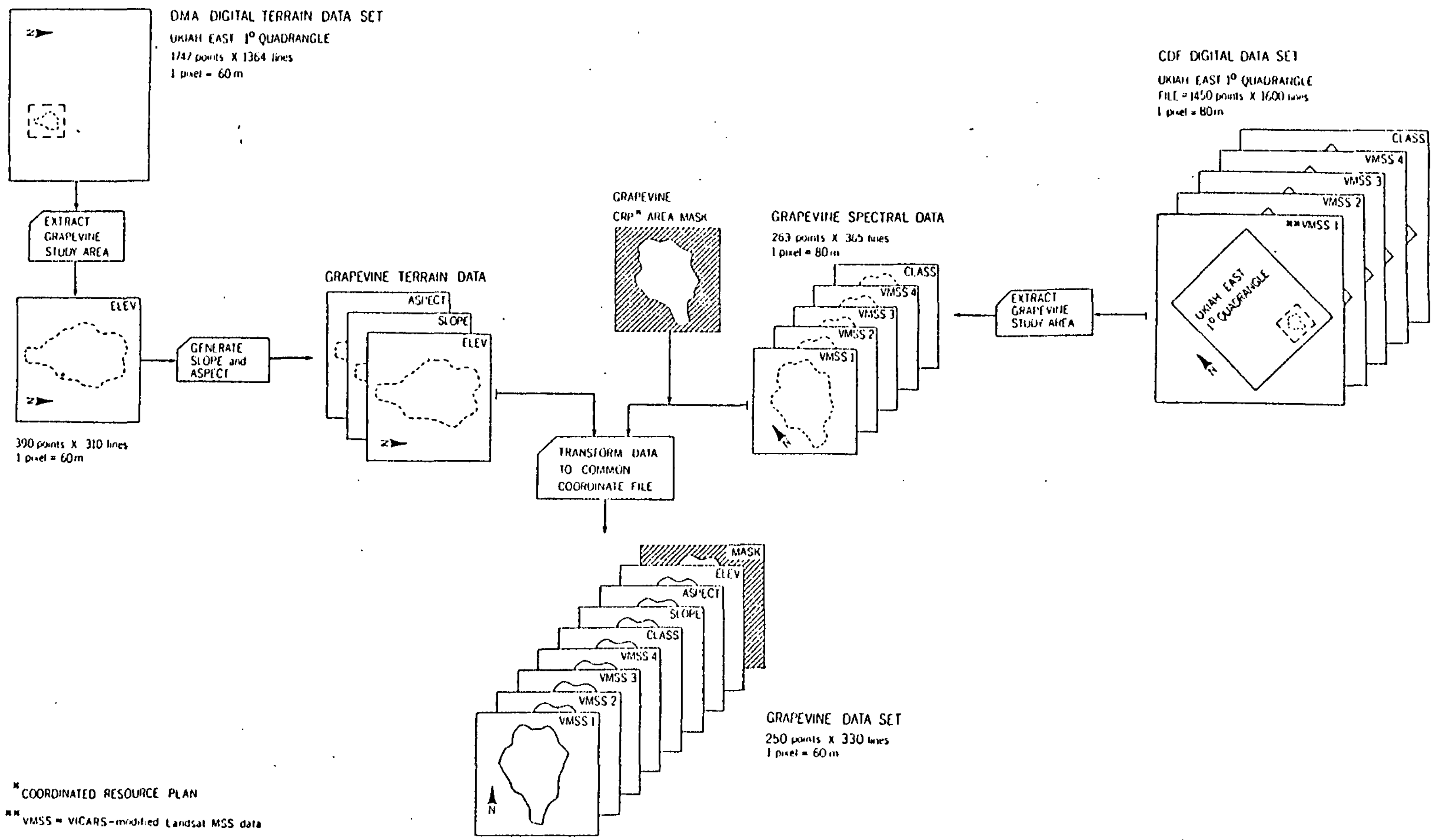


Figure 3. Procedure used to develop the Grapevine data set. See text for details.

tortion. The task of determining the relationships between the two data sets and the UTM grid required the calculation of regression coefficients between (a) CDF point and UTM east, and CDF line and UTM north, and (b) DTT point and UTM east, and DTT line and UTM north. After the regression coefficients were determined, the two data sets could then be registered to a common UTM grid.

The processing phase, during which the data sets were reformatted and overlaid, is generally described below. Specific details of the geographic control and labeling phases are provided in Appendices A and B, respectively. These details are included in order to clearly outline important processing steps which should be performed by remote sensing and data processing specialists before the data can be utilized. Such details are important, and potential users of the CDF data set, or any data set, should understand the complexities involved when generating a data set and then transforming that data into useful resource management information.

2.1 Data Preparation

2.1.1 Reformat the CDF Data Set

The CDF spectral data were received from NASA-Ames on computer compatible tape (CCT) and were converted to the RSRP compatible format. The CCT was organized into five separate files, each 1450 points-by-1600 lines. The first four files corresponded to the four VICAR-modified Landsat MSS bands, while the fifth file corresponded to the unsupervised classification of the first four bands. In order to simplify all subsequent processing and display procedures, all five files were reorganized into one file with five bands. The single file was also reduced in size by extracting a rectangular file 263 points-by-365 lines containing the Grapevine area.

2.1.2 Generate the Digital Mask

Using the RSRP interactive display system, an outline of the study area was digitized, and a mask produced. This mask was applied to the bands of the rectangular file, and effectively deleted all data values falling outside the study area. The mask not only allowed the analyst to quickly grasp the configuration of the study area, but also reduced the amount of extraneous data that are both time-consuming and costly to process.

2.1.3 Reformat the Digital Terrain Data

The digital terrain data covering the study area also had to be extracted from a CCT and converted to the RSRP compatible format. The DTT covered the entire 1° Ukiah East quadrangle, and consisted of approximately 1747 points-by-1364 lines of elevation data, with one pixel equivalent to approximately 60-meters^2. The coordinates of the 1° quadrangle were provided with the DTT data in one-hundredth-of-an-inch units (1 pixel = .01"). The study area (a rectangle drawn around the Grapevine area) was simply measured on the 1:250,000 base map with a scale, and the coordinate pairs of the four corners recorded as .01" increments from the origin. These coordinate pairs were then used to extract a portion from the DTT that encompassed the Grapevine area. The resulting rectangle consisted of 390 points-by-310 lines. The 16-bit elevation data were then reformatted to a single band file on the RSRP system for use and display purposes.

2.1.4 Generate Slope and Aspect Values

In order to enhance the topographic data set, the slope and aspect values of each DTT pixel were generated from the elevation data. The elevation values of a pixel's four adjoining neighbors are used to calculate a normal vector representing a plane that corresponds best to the four elevation values (Figure 4). The slope of the central pixel is defined by the minimum angle between the normal vector and the horizontal plane; the corresponding aspect value is defined by the rotation angle from north of the horizontal projection of the normal vector. The terrain data set, after processing, contained three bands of information (slope, aspect, and elevation), or three "features" for every 60-meter^2 pixel.

2.2 Geographic Control

Geographic control was required in order to establish the relationship between the CDF data set coordinate system of "point and line", the terrain coordinate system of "point and line", and the ground coordinate system of UTM east and north for use in the field. With the establishment of these relationships, a discrete coordinate set, as read off a USGS topographic sheet, could be tied directly to the corresponding coordinate sets in the CDF and DTT data, and vice versa.

The process by which the spectral and terrain data were transformed to common coordinate grid involved the development of a set of regression

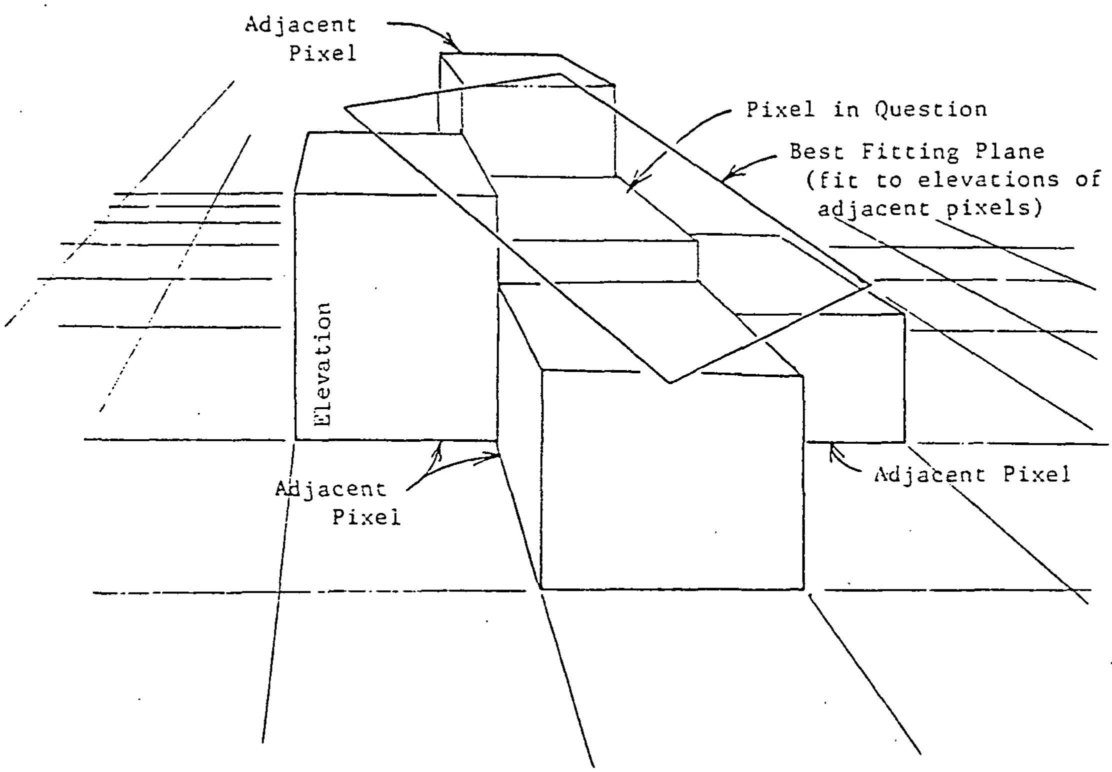


Figure 4. Graphic representation of the slope algorithm, which fits a plane to the four elevation values surrounding the pixel in question. From this algorithm, aspect can also be determined for the center pixel. (after: Henderson, 1980)

models which were tested with a set of 52 control points using a linear least-squares curve fitting program described by Daniel (1977). A detailed account of this process can be found in Appendix B. The regression fits for CDF point and line using UTM east and north as independent variables can be found in Table 1. Table 2 contains the regression fits for DTT point and line, again based on UTM east and north.

2.2.1 Determine Common Pixel Size

Before the transformation coefficients could be applied to the spectral and terrain data, selection of a common pixel size to which the respective data sets could be registered was necessary. If an 80-meter^2 pixel size were chosen, the resolution of the CDF data set would be unchanged, while the resolution of the DTT data set would become more degraded due to data compression during the resampling process. If a 60-meter^2 pixel size were chosen, however, the resolution of the DTT data set would be unchanged, while the resolution of the CDF data would become more generalized due to data repetition during the resampling process. Therefore, the 60-meter^2 pixel size was selected, because the repetition of spectral data was preferred to the degradation of the already gross DTT data.

2.2.2 Transform Data Sets to a Single File

Using the regression coefficients established above, additional regression transformations were performed on the spectral and the terrain data. These regressions created new bands of data by resampling the original data sets using the first set of coefficients. The transformed bands were then written to a new file, thus becoming the new data set. This new file consisted of nine bands of terrain and spectral data, each 250 points-by-330 lines. Once the transformations were completed, all the data had both a common origin and a common pixel size. An analyst could then examine the topographic and spectral features for any pixel within the study area (see Figure 3).

2.3 Reference Grid

As a final step in the preparation of the Grapevine Coordinated Resource Plan data set, a 2000-meter^2 grid was superimposed on the raw and classified data bands. Figure 5 shows the grid's approximate location with respect to the Grapevine study area. This grid was positioned such that it corresponded to the actual UTM grid for the area, as determined from the orthophoto map sheets. The reasons for applying this grid were threefold: (1) to provide a common ground reference system for field crews; (2) for graphic display purposes; and (3) as a sampling frame for use during the labeling phase.

Table 1. Regression fits for CDF point and line using UTM east and north as independent variables.

REGRESSION FIT FOR CDF POINT USING UTM EAST AND NORTH AS INDEPENDENT VARIABLES

Prediction equation: $CDF_{point} = 5462.0 \text{ meters} - .132363[UTM_{east}] + .0182667[UTM_{north}] + 1.929E7[UTM_{east}]^2 - 1.51523E6[UTM_{north}]^2 - 5.74374E7[UTM_{north}][UTM_{east}]$

Analysis of Variance

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F-Value
Regression	2.272E5	5	4.544E4	1.654E5
Residual (error)	1.044E1	38	2.747E-1	
TOTAL	2.272E5	N-1=43		

Range of residuals: -.751 points -to- +1.013 points

Root mean square error: .5242 points

REGRESSION FIT FOR CDF LINE USING UTM EAST AND NORTH AS INDEPENDENT VARIABLES

Prediction equation: $CDF_{line} = 1327.32 \text{ meters} - 4.93507E\text{-}2[UTM_{east}] + 9.43599E\text{-}2[UTM_{north}] + 4.4746E\text{-}7[UTM_{east}]^2 + 8.67168E\text{-}7[UTM_{north}]^2 + 5.57759E7[UTM_{north}][UTM_{east}]$

Analysis of Variance

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F-Value
Regression	6.180E4	5	1.236E4	6.884E4
Residual (error)	6.823	38	1.795E-1	
TOTAL	6.180E4	N-1=43		

Range of residuals: -.969 points -to- +.750 points

Root mean square error: .4237 lines

Table 2. Regression fits for DTT point and line, using UTM east and north as independent variables.

REGRESSION FIT FOR DTT POINT USING UTM EAST AND NORTH AS INDEPENDENT VARIABLES

Prediction equation: $DTT_{point} = -68201.5 + 4.972E{-}4[UTM_{north}] + 1.580E{-}1[UTM_{east}] - 9.377E{-}11[UTM_{north}][UTM_{east}]$

REGRESSION FIT FOR DTT LINE USING UTM EAST AND NORTH AS INDEPENDENT VARIABLES

Prediction equation: $DTT_{line} = -7815.29 + 1.573E{-}2[UTM_{north}] - 4.003E{-}6[UTM_{east}] + 8.005E{-}12[UTM_{north}][UTM_{east}]$

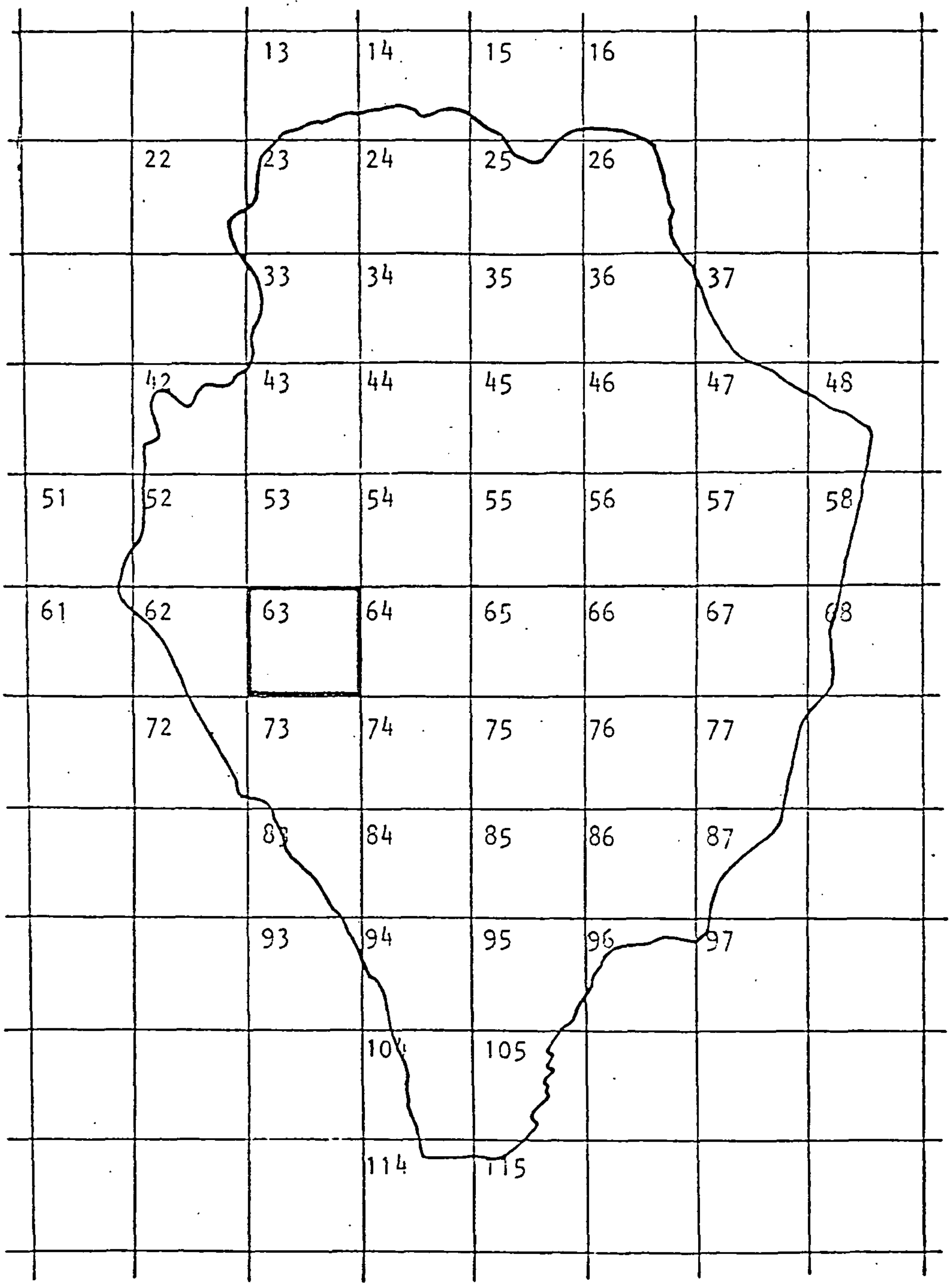


Figure 5. Location of the 2000-meter^2 UTM grid in relation to the Grapevine study area; numbers within each block refer to the block's row and column ID number. The distribution of spectral clusters in Block 63 is shown in Figure 8.

3.0 Labeling Procedure

The labeling phase of the project involved the relabeling of the CDF classified data so as to provide vegetation classes that would be more meaningful for brush management decisions in the Grapevine area. The CDF vegetation classes, arranged in clusters of similar spectral brightness, were derived from a classification algorithm used by the NASA-Ames Research Center on the Center's ILLIAC IV computer system. The resulting clusters were initially labeled by field personnel of the CDF. A description of the original CDF cluster labels can be found in Table 3; the frequency of their occurrence throughout the study area is listed in Table 4. These labels were initially selected with forestry and range applications in mind, and were assigned to clusters within broad ecozones. Figure 6 shows the location of these ecozones throughout California. The labeled clusters were not applicable to the smaller Grapevine area, which makes up only a small portion of the North Central Interior ecozone, as they were found to be too general for our objectives. Therefore, personnel from the RSRP, in cooperation with personnel from the Colusa County SCS field office, met and defined a classification scheme that would be more appropriate for brush management in the Grapevine area. At the meeting it was concluded that refinement of the broad brush classes, as well as the general hardwood classes, was required. The resulting brush management classes are listed in Table 5.

In order to facilitate labeling, several ancillary products were prepared and referenced throughout the labeling procedure. The spectral aids included ratios of band means (Band 4/Band 2, and Band 1/Band2), and Euclidean Brightness values for each cluster. Other interpretation aids included orthophoto and U-2 coverage.

The clusters were then labeled by 2000-meter^2 grid block. The actual labeling procedure, which incorporates the ancillary data and line printer maps, is fully described in Appendix C.

Each cluster type was labeled in at least five blocks in order to ascertain the cluster's integrity throughout the study area; that is, the cluster should represent the same vegetation type and condition in every spectral block that it occurs. As was often the case, clusters did not represent pure vegetation types. Therefore, the analyst had to decide which brush management label described the cluster best in the majority of the sample.

Table 3. Class descriptions used by CDF personnel to label the spectral clusters from the unsupervised classification of the statewide Landsat digital mosaic.

CLASS DESCRIPTIONS

A. Bare rock

B. Water

C. Agriculture (pattern recognition)

D. Urban (may be residential and/or commercial)

E. Alkali flats

F. Barren (predominantly bare soil, less than 5% vegetative cover)

G. Grassland - Vegetation predominantly grass. Cover greater than 5%. May be annual or perennial grasslands. Less than 10% tree cover. May include herbaceous vegetation.

H. Desert shrub - Vegetation consists of xeric shrubs, generally open with much bare soil and desert pavement exposed. However, dense stands may occur. Vegetation ranges from .5 to 3 meters tall. Less than 10% tree canopy. Generally found on flat or slightly sloping terrain.

I. Brush - Open to dense (greater than 5% ground cover) evergreen or deciduous shrubs, rarely more than 5 meters tall (usually 1-3 meters). May have herbaceous understory. Less than 10% tree canopy. This includes riparian vegetation along waterways.

J. Hardwood-woodland - Scattered hardwoods (deciduous and evergreen), 10-25% canopy closure. May have grass or brush understory.

K. Conifer-woodland - Scattered conifers, 10-25% canopy closure, often with an herbaceous or brush understory.

L. Hardwood - Greater than 25% canopy closure of hardwood species. Less than 20% conifer in the stand. May have an herbaceous or brush understory.

M. Hardwood-conifer - Greater than 25% canopy closure, with hardwoods comprising greater than 50% but less than 80% of the stand. Conifers comprise 20-50% of the stand. There may be an herbaceous or shrub understory.

N. Conifer-hardwood - Greater than 25% canopy closure, with conifer species comprising greater than 50% but less than 80% of the stand. Hardwood species comprise 20-40% of the stand. There may be an herbaceous or shrub understory.

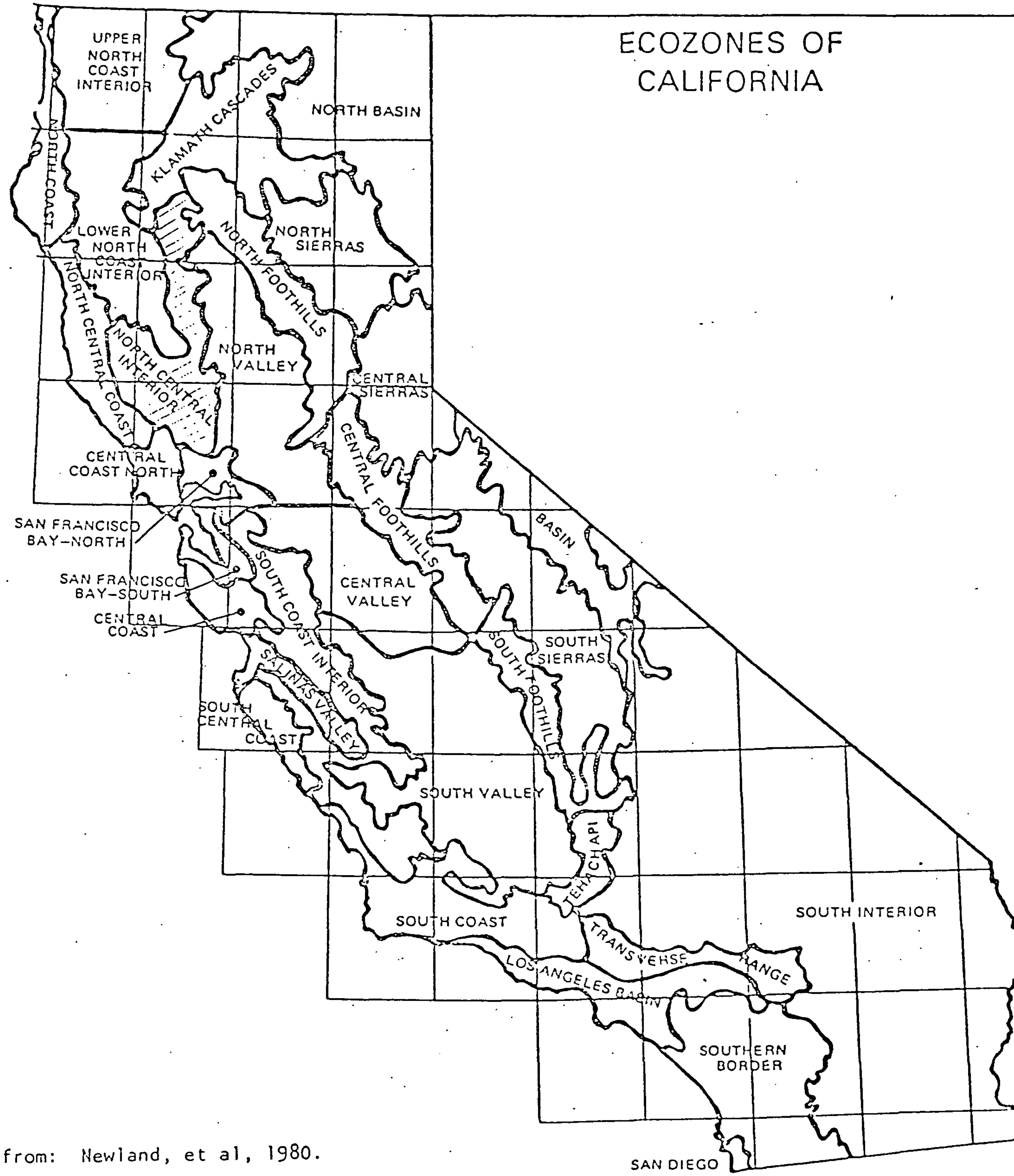
O. Conifer - greater than 25% crown closure of conifer species. Less than 20% hardwood in the stand. There may be an herbaceous or brush understory.

Table 4. CDF data set cluster counts for the Grapevine study area.

GRAPEVINE COORDINATED RESOURCE PLAN AREA

UKIAH EAST QUADRANGLE

CLUSTER NUMBER	SAMPLE COUNT	CDF LABEL
58	0	water
59	369	brush
60	5622	hard woodland
61	2610	brush
62	1648	brush
63	0	hardwood conifer
64	0	hardwood conifer
65	3177	hard woodland
66	32	brush
67	0	hardwood conifer
68	4276	hard woodland
69	0	hardwood conifer
70	0	hardwood
71	2698	hard woodland
72	0	conifer woodland
73	175	brush
74	2907	hard woodland
75	0	hardwood
76	2978	hard woodland
77	0	hard woodland
78	3879	grass
79	0	hardwood
80	17	grass
81	0	agriculture
82	1451	grass
83	2512	grass
84	2847	grass
85	0	agriculture
86	587	grass
87	813	grass
88	2848	grass
89	45	grass
90	132	barren
91	1444	barren
92	61	barren



from: Newland, et al, 1980.

Figure 6. Arrangement of the CDF-defined ecozones throughout California. The North Central Interior ecozone (cross-hatched) contains the Grapevine study area.

Table 5. Brush management classes for the Grapevine study area.

GRAPEVINE COORDINATED RESOURCE PLAN AREA

BRUSH MANAGEMENT CLASSES

VEGETATION

Chaparral
- chamise - pure *(Adenostoma fasciculatum)*
- chamise/oak *(A. fasciculatum, Quercus sp.)*
- brush *(A. fasciculatum, Arctostaphylos sp., Aesculus californicus, Ceanothus sp., Cercocarpus betuloides, Eriodictyon californicum, Arbutus Menziesii, Photinia arbutifolia)*
- brush/hardwood mixture
- brush/softwood mixture *(Pinus sabiniana)*

Woodland
- hardwood - pure *(Quercus sp., Acer sp., Lithocarpus densiflora)*
- oad woodland *(Quercus sp., Avena sp., Bromus sp., Hordeum sp., Festuca sp.)*

Grassland
- grassland - pure *(Avena sp., Bromus sp., Hordeum sp., Festuca sp.)*
- grassland/hardwood
- grassland/riparian

Other
- barren
- water
- agriculture
- urban

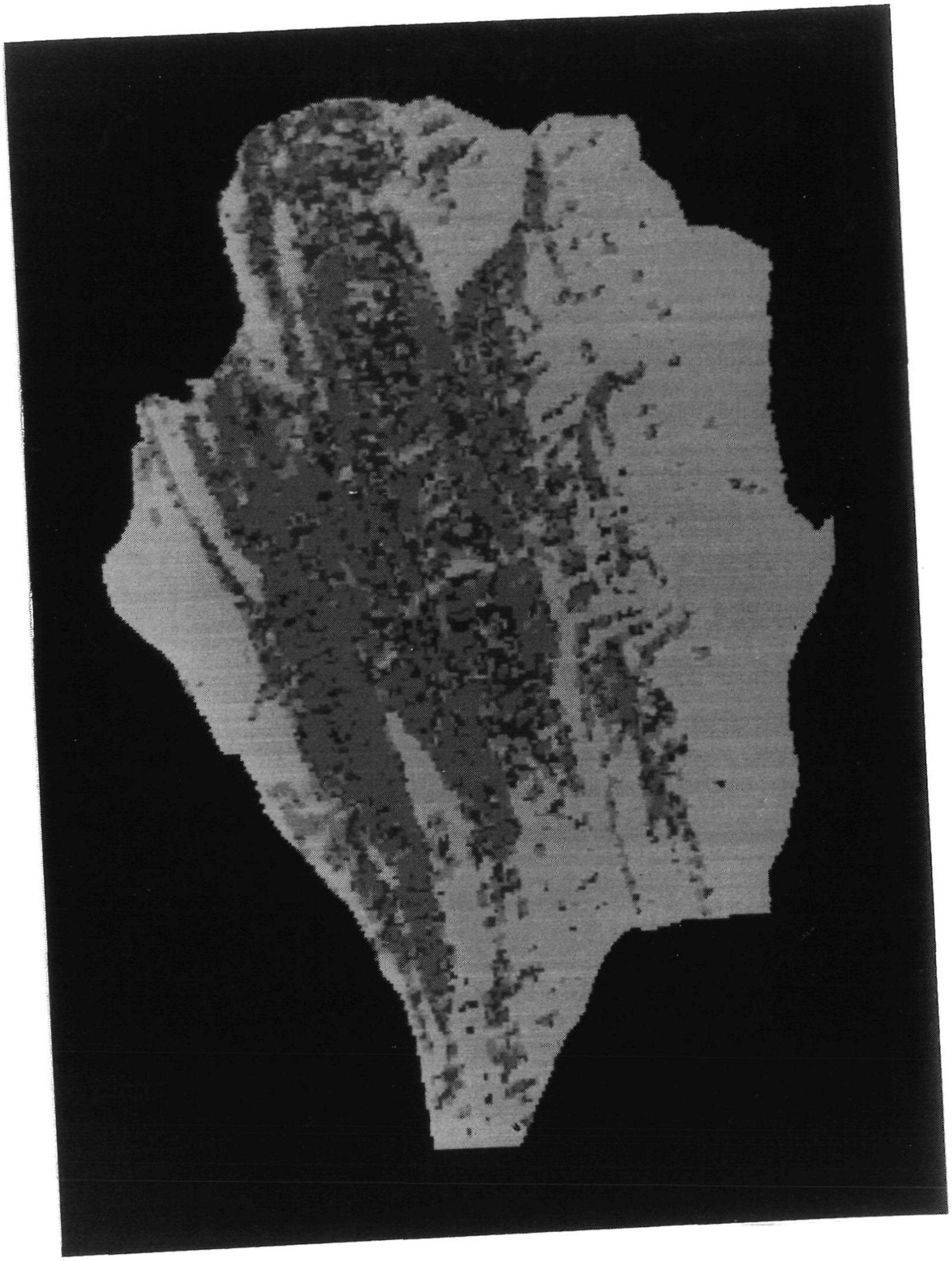
Once the analyst attached brush management labels to all the vegetation classes, the classified band in the data set was color-coded to reflect the new labels. Figure 7 shows the results of the labeling procedure, and the distribution of the brush management classes throughout the study area. Table 6 offers a comparison between the original CDF labels and the modified brush management labels that were assigned to the 35 clusters in the study area.

4.0 Evaluation of the Grapevine Data Set

4.1 The Spectral Portion

The most time-consuming step of the Grapevine data set preparation phase involved the labeling procedure. During this procedure, the analyst noted that many seemingly pure stands of chamise, which in all likelihood would have been lumped together in homogeneous groups, had instead been broken out into five or six spectral classes. Conversely, predominantly west ridges, with chamise on the south aspect and a brush/hardwood mixture on the north aspect, did not reflect this floral patchwork; instead, this situation was frequently represented by a single vegetation class. The fact that the same CDF cluster label was applied to several different combinations of vegetation and aspect made the labeling procedure ambiguous at times, and the inconsistencies provoked much discussion concerning the merits of the spectral classification. Unfortunately, the algorithm used to classify the spectral data often had to cluster spectral data whose values were very close; as a result, the classifier frequently split data that may have been pure vegetation classes. There were also a maximum number of classes allowed per ecozone, which may have resulted in the mixture of vegetation types that had close spectral means. The analyst could only examine each cluster in a variety of locations and label the cluster according to the predominant vegetation type found to be represented by that cluster.

As the classification algorithm was applied by ecozone, it is understandable that many types of vegetation would necessarily be generalized into only a few classes. Of concern in this report is the integrity of the few (35) classes that the classifier delineated in the Grapevine area. In addition to the classification problems stated above, the anomalies found are probably due to the high degree of dissection found within the Grapevine area: eighty-meter^2



brush -- light yellow
chamise -- red
brush/hardwood mix -- orange
chamise/oak -- purple
oak woodland -- blue
grass, bare soil -- yellow
other (outside ecozone) -- white

Figure 7. Distribution of brush management classes in the Grapevine study area. The image was photographed off the RSRP color monitor. See Table 5 for a description of the vegetation classes by species.

Table 6. A comparison of the CDF and brush management labels that were assigned to the 35 clusters in the Grapevine study area.

CLUSTER NUMBER	SYMBOL	CDF LABEL	BRUSH MANAGEMENT CLASS
58	1	water	*
59	2	brush	brush
60	3	hardwood woodland	chamise
61	4	brush	chamise
62	5	brush	brush/hardwood mixture
63	6	hardwood conifer	*
64	7	hardwood conifer	*
65	8	hardwood woodland	chamise/oak
66	9	brush	brush with digger pine
67	A	hardwood conifer	*
68	B	hardwood woodland	brush/hardwood mixture
69	C	hardwood conifer	*
70	D	hardwood	*
71	E	hardwood woodland	oak woodland
72	F	conifer woodland	*
73	G	brush	brush
74	H	hardwood woodland	chamise/oak
75	I	hardwood	*
76	J	hardwood woodland	oak woodland
77	K	hardwood woodland	*
78	L	grass	grassland
79	M	hardwood	*
80	N	grass	grassland
81	O	agriculture	*
82	P	grass	grassland
83	Q	grass	grassland
84	R	grass	grassland
85	S	agriculture	*
86	T	grass	grassland
87	U	grass	grassland
88	V	grass	grassland
89	W	grass	grassland
90	X	barren	barren
91	Y	barren	barren
92	Z	barren	barren

* indicates that cluster did not appear in the study area.

pixel resolution is not adequate for the drainage density of the area, and leads to severe generalization where ridges are too close together to permit spectral representation of both north- and south-facing slopes.

Aside from topographic dissection, error may be attributed to the slight misregistration between Landsat bands that occurred during the mosaicking of the CDF data set. This misregistration, which looks about one or two pixels, can be detected around the swathed small grain fields located to the west of the study area. Slight band misregistration is difficult - if not impossible - to avoid, and generally is a fact remote sensing specialists accept. Unfortunately, misregistration of spectral data in a heavily dissected area (such as the Grapevine area) results in degradation of spectral clarity, especially around shadows. Obviously, the misregistration of pixels also affects the spectral classification of the data, as the clustering algorithm uses the spectral values of all four bands for a given pixel in order to determine cluster means and standard deviations. Any misregistration would result in a spectral shift in one of the four bands, causing the classifier to cluster pixels which contain band values from a neighboring pixel. The effects of misregistration can be alleviated somewhat by assigning labels according to relative cluster ranking, rather than the absolute values.

One can theorize that the class fragmentation of "pure" chamise stands could be attributed to the presence of different age classes or conditions within those stands, rather than to band misregistration. In order to test this theory, further clustering was performed on the classified data using an algorithm that is part of the RSRP software package. The means and standard deviations between bands for each of the original brush and hardwood classes were used as a seed, and by adjusting the minimum threshold values permitted between bands, it was theoretically possible to divide and/or recombine the classes further. If the fragmentation really represented varying stand conditions, it was hoped that by refining the clusters, more discrete patterns of vegetation could be discerned. The least we could hope for would be the ability to differentiate the north- and south-facing vegetative types.

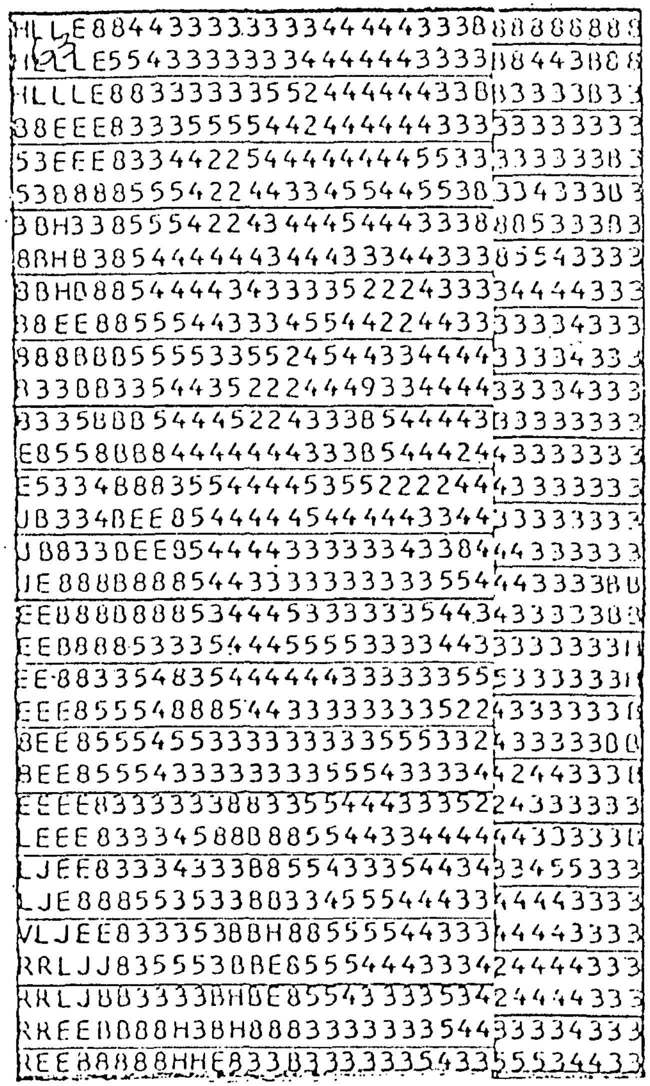
Unfortunately, the clusters exhibited low variability; that is, the distance between cluster means was very small. Therefore, the resulting classification was very similar to the original CDF product and did not provide a more informative pattern of clusters. Figure 8 shows (a) the original CDF class map for Block 63, and (b) the results of the additional clustering. There was no significant advantage noted by the analyst to the re-clustered data, and no aspect-related vegetative component could be discerned on the refined cluster map.

With assistance from the Soil Conservation Service Field Office in Colusa, RSRP personnel spent several days in the field, collecting ground data points. These ground truth samples, which were selected randomly, roughly traversed a cross-section through the most rugged brush stands. The ground crew located the points on aerial photography, and then transferred the points to orthophoto sheets; the latter were used to derive UTM coordinates for the ground samples. Later in the office, the UTM coordinate pairs were converted to the computer file coordinates. Once the file coordinates were determined, the analyst keyed in the coordinate pairs, and was able to retrieve the vegetative, topographic, and spectral values for each point.

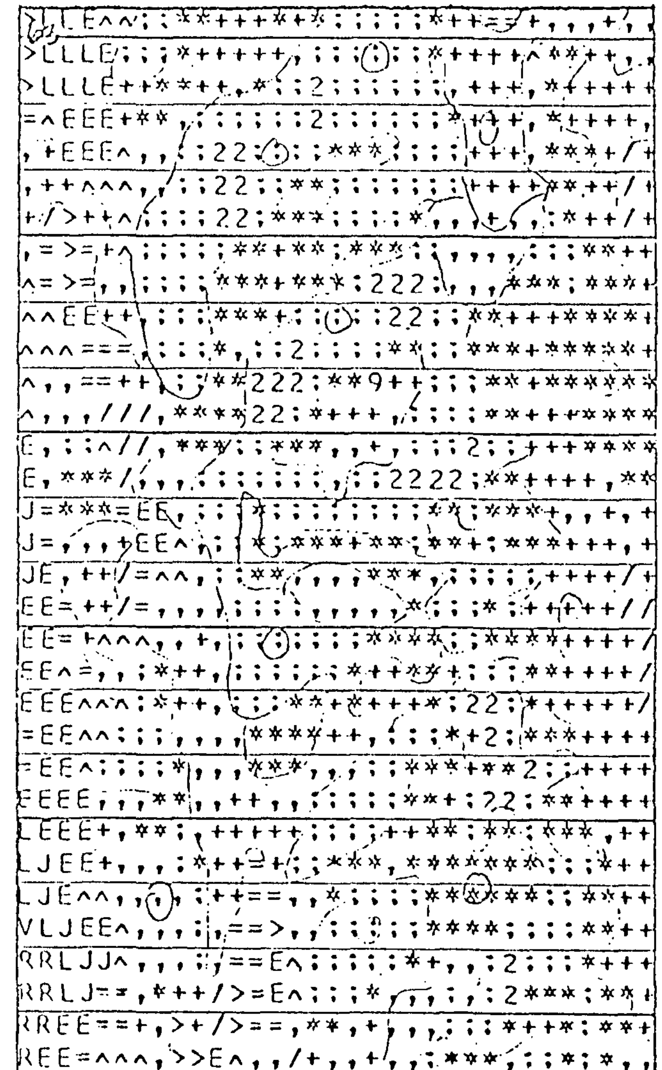
In all, 55 ground samples were taken. The first step in the analysis was to compare the brush management cluster labels with what the field crew observed. Table 7 shows the distribution of the observed versus the classified cluster labels. No conclusive results can be made from only 55 points; however, some general ovservations can be made, as indicated below.

Of the major brush classes, the chamise and brush/hardwood mixture classes were most frequently at odds with the ground observations. This was not unexpected, as it had been noted during the labeling phase that clusters often represented a variety of vegetation types; the analyst resolved this by assigning a label to each cluster that was most frequently correct. The error associated with the chamise and brush/hardwood classes could be partly attributed to mislabeling, as mentioned above. Another confounding effect could be topographic - specifically, aspect-related. Labeling accuracy was then examined in terms of aspect. In the majority of cases, chamise was most frequently mislabeled on west aspects; the brush/hardwood class was most often mislabeled on the northwest and west aspects. The brush/digger pine class tended to be labeled as chamise on northwest aspects, and the brush/hardwood class was often called chamise on the northwest and west aspects.

Although there was little agreement between the classified labels and the



a) line printer map showing original classification of the CDF data set for Block 63.



b) line printer map showing results of re-clustering of the CDF classified data for Block 63.

Figure 8. Line printer maps for Block 63 showing the original CDF cluster distribution and the results of re-clustering of the CDF classified data.

Table 7. Observed vegetation types versus classified vegetation labels for 55 ground reference points.

brush management class \ ground reference	grassland	oak woodland	chamise/oak	chamise	brush/hardwood	brush	brush/pine	barren
barren								
brush/pine								
brush					1		1	
brush/hardwood		1		2	4	2	3	2
chamise		1	1	3	6		7	
chamise/oak		2		1	1		5	
oak woodland		6	1		1			
grassland		4						

observed vegetation types, the difference was seldom extreme; digger pine was often called oak, and chamise was frequently confused with brush. There were few cases in which oak-woodland and chamise were confused. It was also noted that small areas with a hardwood component tended to be missed by the clustering if surrounded by chamise; this effect was pronounced on the steeper slopes.

4.2 The Terrain Portion

Preliminary analysis made it clear early on in the research that the DTT data would not be of use in the Grapevine area. The DTT tapes were modeled on USGS topographic sheets at the base scale of 1:250,000, with elevation values digitized and interpolated at 200-foot contour intervals. The slope and aspect data used in the Grapevine data set were derived from DTT elevation values. Obviously, the accuracy of the elevation, slope, and aspect models is dependent on the accuracy of the original map base itself, with further degradation of detail caused by the 200-foot contour interpolation algorithm used.

The Grapevine study area, which consists of many steep, parallel-trending ridges, proved to be too finely dissected for accurate representation by the DTT interpolation algorithm. As a result, most of the ridge lines were truncated because the algorithm assigned elevation values to individual pixels that were the average of the elevations of the two nearest (200-foot) contour lines. Figure 9 shows how a transect might be represented by the DTT terrain model.

The 200-foot contour interval also proved to be inadequate for representing a meaningful net of elevation values upon which to base the slope and aspect models. The aspect values, which reflect the direction of slope, were very inaccurate as the ridges were often truncated, thereby creating "flat" aspects *in lieu* of junctions of north- and south-facing slopes. One can readily see the difference between the DEM and DTT aspect data in Figure 10. The fine detail of the DEM aspect coverage makes the photograph seem almost three dimensional. The lack of detail in the DTT data would jeopardize the ability to discriminate vegetation types by aspect, an important factor with such aspect-related vegetation as chamise. The slope values, which would normally be useful for erosion control purposes and to determine where to use the appropriate type of mechanized brush modification, were inadequate for these purposes.

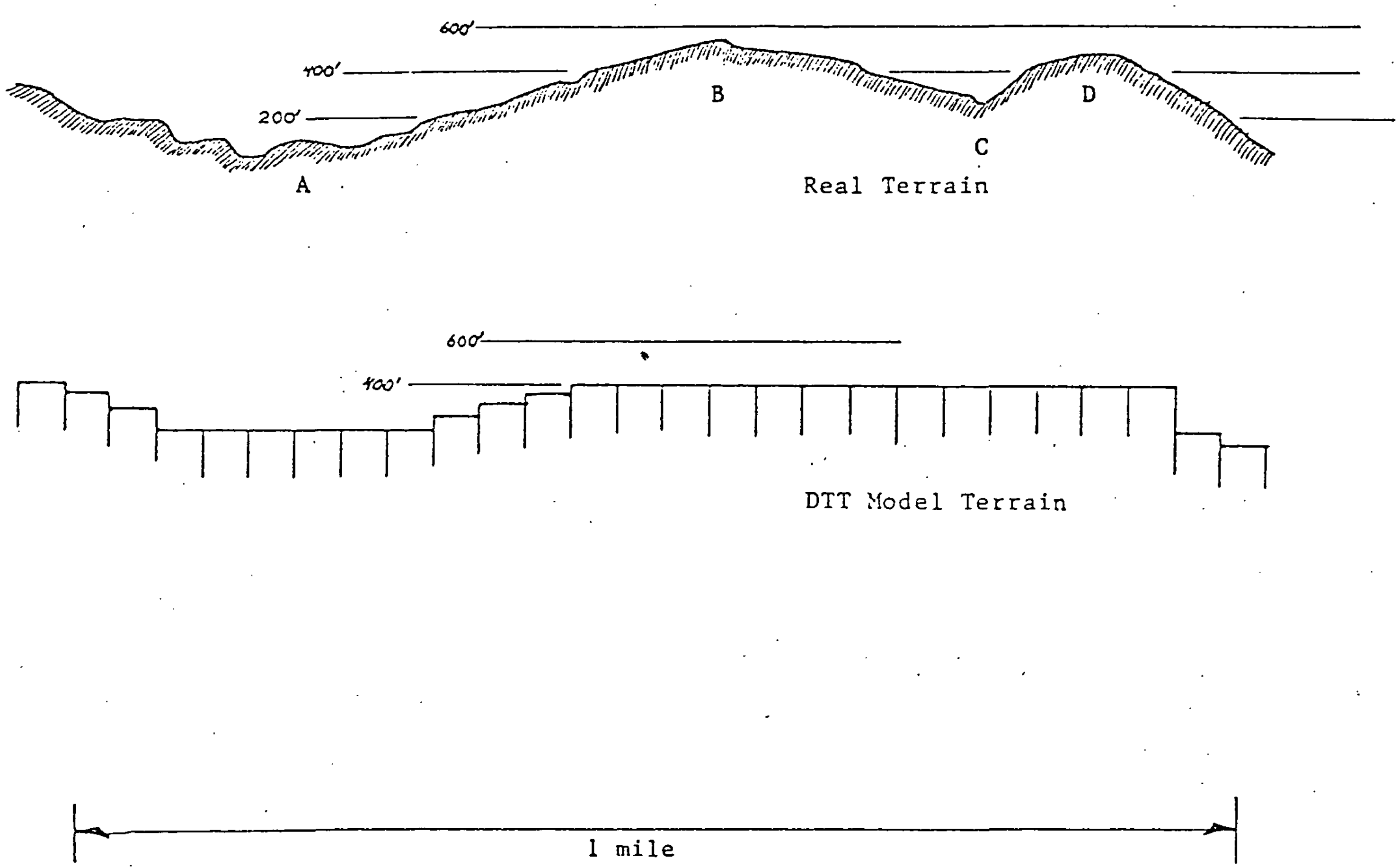
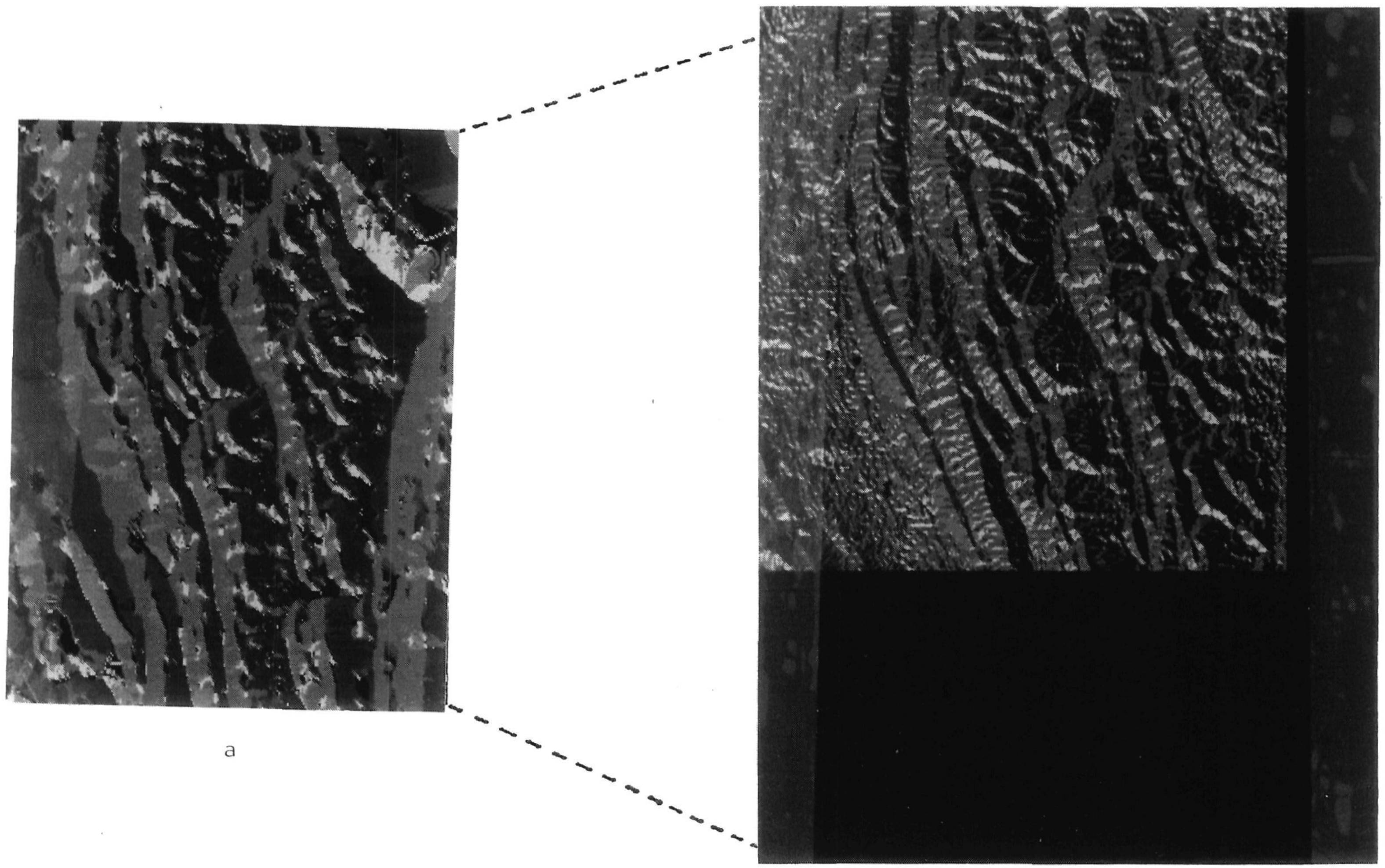


Figure 9. Transect illustrating the topographic representation of the DTT versus actual terrain; note that the DTT's interpolation algorithm in some cases truncates ridge tops and fills valleys. (after: Henderson, 1980)



a

b

Figure 10. DTT (a) and DEM (b) aspect coverage for the Grapevine study area. Note that the DEM data were only acquired for one $7\frac{1}{2}$-minute quadrangle, while the DTT data cover the entire study area, denoted by the dashed lines.

As an alternative to the DTT data, Digital Elevation Madel (DEM) data were purchased from USGS. The DEM data have a distinct advantage over the DTT data in terms of accuracy, as the DEM data are digitized directly from stereo photography to produce a 30-meter^2 pixel base (versus the DTT's 60-meter^2 pixel size). Figure 11 graphically demonstrates how the DTT and DEM data would represent the same transect. The horizontal control of the DEM data is also very good: for the Lodoga SW quadrangle (which contains most of the Grapevine study area), the root mean square (RMS) error averaged 4.8 meters. Horizontal control for the DTT data was virtually nonexistent.

The terrain data were also analyzed, but not in the same manner as the spectral portion. Field checking of the DEM's 30-meter^2 elevation, slope, and aspect values would have been too costly to perform, assuming it could have been done without $7\frac{1}{2}$-minute topographic coverage of the area. Instead, it was assumed that the DEM data, with the low RMS error, were as accurate as field measurement, and more accurate than topographic map measurement on a 15-minute map base.

The DEM data became the primary terrain data set, and were added to the Grapevine information system. These data were used in chi-square analysis that was performed on aspect and vegetation classes. In addition, the DEM data were used as input into an RSRP algorithm that calculates true acreage using slope values. Table 8 shows the conversion factors needed to derive true acreage from planimetric pixels. This information could help resource managers deploy personnel and equipment, as the true acreage of a proposed brush modification plan may entail more area than one would estimate using a planimetric map. The difference in area may be significant in terms of equipment costs, as bulldozers and other large equipment used for chaining and crushing brush are very expensive to operate.

The DEM data were also used to evaluate the DTT data set. Tables 9, 10, and 11 represent scatter plots that compare DEM versus DTT elevation, DEM versus DTT slope, and DEM versus DTT aspect, respectively. Although there is little correlation between the two data types, a few observations can be made concerning the comparison. For example, it can be seen in Table 9 that the DTT elevation data correlate somewhat with the DEM data at certain step intervals. These intervals correspond to the DTT 200-foot contour intervals to which the elevation values were interpolated during the creation

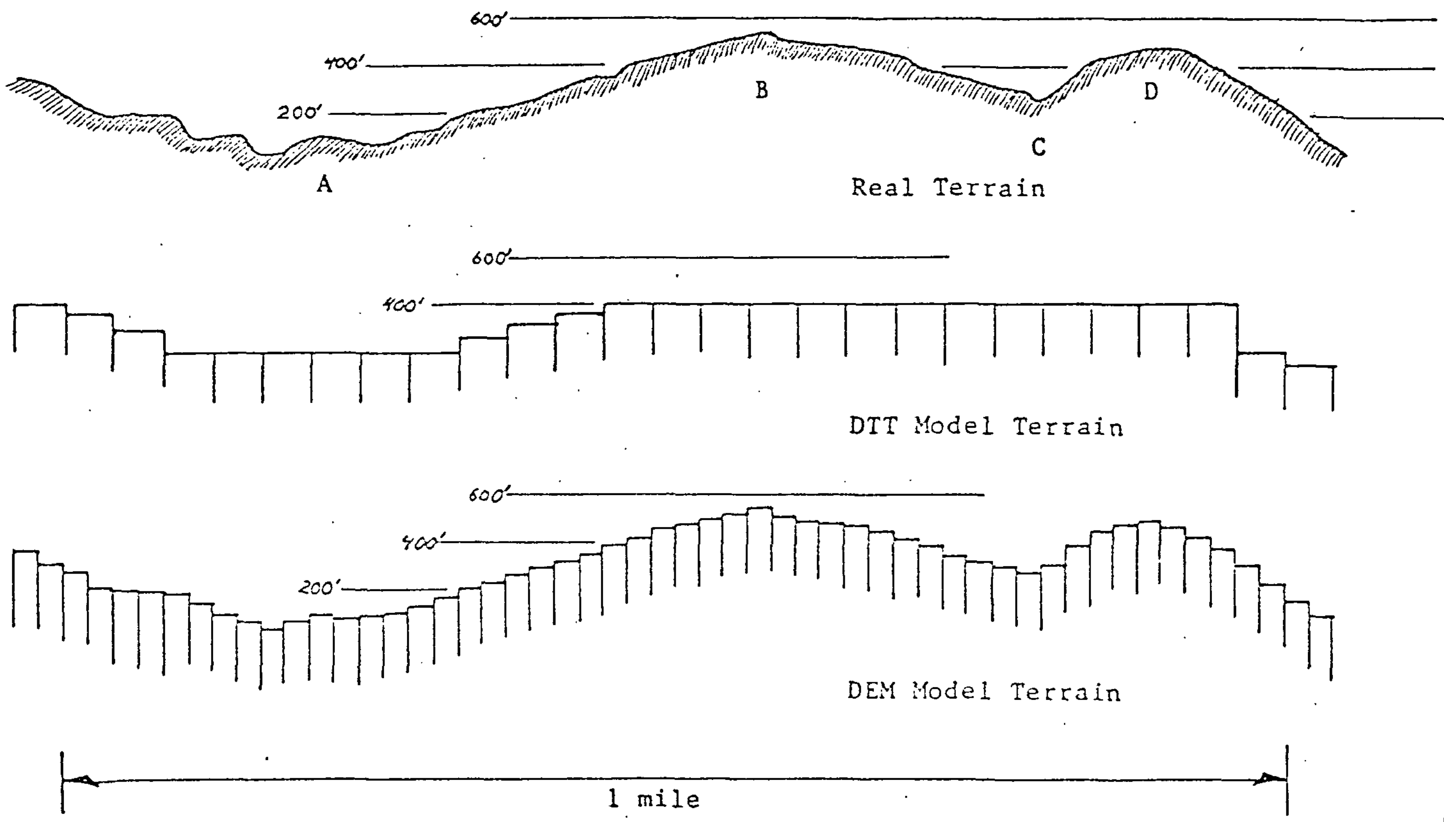


Figure 11. DTT versus DEM terrain models shown over an imaginary transect. Note that the DTT's interpolation algorithm in some cases truncates ridge tops and fills valleys. By contrast, DEM terrain models represent the real terrain with excellent accuracy. (after: Henderson, 1980)

Table 8. Acreage conversion chart based on pixel slope values. Using these values, one can easily convert planimetric area to actual acreage.

Percent Slope	Multiplication Factor	Percent Slope	Multiplication Factor
0	1.00000	65	1.19269
1	1.00005	66	1.19816
2	1.00020	67	1.20370
3	1.00045	68	1.20930
4	1.00080	69	1.21495
5	1.00125	70	1.22065
6	1.00180	71	1.22642
7	1.00245	72	1.23223
8	1.00319	73	1.23810
9	1.00404	74	1.24403
10	1.00499	75	1.25000
11	1.00603	76	1.25602
12	1.00717	77	1.26210
13	1.00841	78	1.26823
14	1.00975	79	1.27440
15	1.01119	80	1.28062
16	1.01272	81	1.28689
17	1.01435	82	1.29321
18	1.01607	83	1.29958
19	1.01789	84	1.30599
20	1.01980	85	1.31244
21	1.02181	86	1.31894
22	1.02391	87	1.32548
23	1.02611	88	1.33207
24	1.02840	89	1.33869
25	1.03078	90	1.34536
26	1.03325	91	1.35207
27	1.03581	92	1.35882
28	1.03846	93	1.36561
29	1.04120	94	1.37244
30	1.04403	95	1.37931
31	1.04695	96	1.38622
32	1.04995	97	1.39316
33	1.05304	98	1.40014
34	1.05622	99	1.40716
35	1.05948	100	1.41421
36	1.06283	101	1.42130
37	1.06625	102	1.42842
38	1.06977	103	1.43558
39	1.07336	104	1.44277
40	1.07703	105	1.45000
41	1.08079	106	1.45726
42	1.08462	107	1.46455
43	1.08853	108	1.47187
44	1.09252	109	1.47922
45	1.09659	110	1.48661
46	1.10073	111	1.49402
47	1.10494	112	1.50146
48	1.10923	113	1.50894
49	1.11360	114	1.51644
50	1.11803	115	1.52397
51	1.12254	116	1.53153
52	1.12712	117	1.53912
53	1.13177	118	1.54674
54	1.13649	119	1.55438
55	1.14127	120	1.56205
56	1.14612	121	1.56974
57	1.15104	122	1.57747
58	1.15603	123	1.58521
59	1.16108	124	1.59298
60	1.16619	125	1.60078
61	1.17137	126	1.60860
62	1.17660	127	1.61645
63	1.18190		
64	1.18727		

Table 9. DTT versus DEM elevation coverage of the Grapevine study area.

DTT ELEVATION (FEET)	0	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500
2400																						3	27	19	5	
2300																						19	44	81	14	
2200																				19	359	828	520	233	57.	6
2100																			2	253	437	377	344	275	30	2
2000																	11	219	1164	2260	2061	1562	936	410	37	
1900																	50	688	1379	1123	1108	870	544	73		
1800																157	1031	3388	2894	2666	2050	1367	420	11		
1700															45	417	1548	1643	1575	1074	788	345	20			
1600													1	96	925	3372	4142	4014	2537	1815	690	60				
1500													37	344	1492	2524	1993	1518	891	381	51	3				
1400										3	54	115	563	5419	16389	6262	3157	1539	460	100	3					
1300										5	40	284	695	7520	7436	1247	633	251	51	9						
1200									31	202	674	1263	6005	8251	5124	1232	449	137	22							
1100								5	200	313	776	842	1198	1436	731	241	59	3								
1000								99	557	1083	1888	2879	3124	1503	480	85	10									
900								187	539	974	1423	1367	850	236	23											
800						25	159	1549	2945	3871	2737	1362	391	21												
700						46	550	1748	1986	1339	405	51														
600						1995	5241	5715	2728	692	114	20	4													
500					137	3294	2338	488	63																	
400					5944	4039	707	142																		
300																										
200																										
100																										
0																										

DEM ELEVATION (FEET)

Table 10. DTT versus DEM slope coverage of the Grapevine study area.

DTT PERCENT SLOPE											
100			1	1	2			4			
90					1	1	2				
80		6	9	8	3	4	2	4			
70	1	32	47	98	72	98	66	38	8	5	1
60	1	222	299	360	409	329	245	127	36	4	
50	9	608	1080	1517	1704	1460	851	347	102	9	
40	7	1933	3375	4651	5243	4102	2187	835	196	36	2
30	32	3216	5977	8233	9077	6333	3039	1001	254	25	1
20	112	7371	10424	10978	9138	5567	2267	689	168	34	1
10	1201	34561	17697	11640	8066	4308	1750	511	100	11	2
flat	184	5476	4961	4420	3505	2022	816	304	60	13	
	flat	10	20	30	40	50	60	70	80	90	100

DEM PERCENT SLOPE

Table 11. DTT versus DEM aspect coverage of the Grapevine study area.

DTT ASPECT		DEM ASPECT								
		FLAT	N	NE	E	SE	S	SW	W	NW
	NW	502	1166	1774	1106	473	512	1673	3057	1897
	W	1429	2345	3492	3959	1711	2442	5793	8211	3827
	SW	476	1103	2739	3613	1592	2014	4226	3415	1510
	S	202	1164	2280	2733	1264	1396	1773	1172	790
	SE	111	1445	3008	3722	1913	1374	1469	812	644
	E	601	4189	10492	12152	5762	4001	4035	2736	2310
	NE	928	4922	9511	9110	5248	3805	4124	4118	3682
	N	304	1477	2249	1545	684	583	1166	1779	1743
	FLAT	504	1867	3752	4281	1896	1713	3097	2837	1814

of the DTT data. In Table 10, the correlation between DEM and DTT slope classes is slightly better at the lower slope values. There are also very few outliers, indicating that the DTT data have a certain amount of accuracy associated with them. A brief examination of Table 11 indicates that the correlation between DEM and DTT aspect values is best on northeast, east, and west aspects.

As the terrain data and spectral data exist together in the Grapevine data set, it is easy to combine the two types of data in order to learn more about the study area. For example, in order to test a theory that vegetation is correlated with aspect, a chi-square analysis was performed using the spectral and DEM terrain data. Table 12 contains the output from the chi-square run. The expected value is that which one would expect given the distribution was purely random. The larger the difference between the observed and expected, the better the chances that the distribution of vegetation classes is related to aspect, and not a function of randomness.

5.0 Recommendations

Coordinated Resource Planning, which was federally mandated in a 1975 Memorandum of Understanding (see Appendix A), requires the processing and utilization of resource information for each conservation district. We felt that it was important to evaluate the utility and application feasibility of existing data sets in order to expedite planning while keeping costs at a minimum. Despite the rather conditional success we had using these data sets in the Grapevine area, we still feel that this type of data set can work, provided the user is cognizant of the shortcomings inherent in this type of data.

5.1 The CDF Data Set

The CDF data set seems to have been adequate for the Grapevine study, as there was little actual disagreement between the CDF labels and the analyst-assigned brush management labels. The CDF-defined "hardwood woodland" classes were often identified by the analyst as brush or chaparral classes, but this was due to some extent to differences in the way the classes were defined, rather than to erroneous labeling.

Prior to final evaluation, our initial reaction is that the CDF spectral data set will be satisfactory for Coordinated Resource Planning in Colusa County; preliminary field checking of the RSRP image products by SCS personnel has shown the data to be promising. It is important, however, to point out some strengths and weaknesses of the CDF data set so that a potential user can decide if this data set would be effective for his purposes.

Table 12. The chi-square test as run on the contingency table for vegetation and aspect for the Grapevine study area.

COL1 ASPECT#9 VERSUS VEGETATION#6

	BRUSH	CHAMISE	BRUSH/ HARDWOOD	CHAMISE/ OAK	OAK/ WOODLAND	GRASSLAND	ROW SUM
FLAT	17	558	412	530	504	1064	3085
EXPECTED	41.202	588.845	423.751	435.196	406.011	1189.994	
CHI SQ	14.216	1.616	.326	20.652	23.649	13.340	73.799
NORTH	66	744	366	292	257	544	2269
EXPECTED	30.304	433.092	311.667	320.084	298.619	875.234	
CHI SQ	42.048	223.194	9.472	2.464	5.800	125.356	408.334
NORTHEAST	110	1440	1060	952	743	2144	6449
EXPECTED	86.130	1230.944	885.825	909.750	848.742	2487.608	
CHI SQ	6.615	35.505	34.247	1.962	13.174	47.462	138.965
EAST	139	1594	1443	1331	1290	4754	10551
EXPECTED	140.915	2013.908	1449.270	1488.413	1388.598	4069.895	
CHI SQ	.026	87.553	.027	16.648	7.001	114.991	226.245
SOUTHEAST	20	438	405	420	456	1326	3065
EXPECTED	40.935	585.028	421.004	432.375	403.379	1182.279	
CHI SQ	10.707	36.951	.608	.354	6.864	17.471	72.955
SOUTH	40	469	393	400	410	1290	3002
EXPECTED	40.093	573.003	412.350	423.487	395.088	1157.978	
CHI SQ	.000	18.877	.908	1.303	.563	15.052	36.703
SOUTHWEST	40	863	632	687	714	2050	4986
EXPECTED	66.591	951.696	684.870	703.367	656.199	1923.277	
CHI SQ	10.618	8.266	4.081	.381	5.091	8.350	36.788
WEST	81	1308	901	1016	968	2814	6988
EXPECTED	93.329	1333.825	959.862	985.786	919.678	2695.520	
CHI SQ	1.629	.500	26.292	.926	2.539	5.208	37.094
NORTHWEST	63	818	412	456	334	650	2733
EXPECTED	36.501	521.658	375.401	385.540	359.685	1054.215	
CHI SQ	19.238	168.346	3.568	12.877	1.834	154.987	360.859
COLUMN SUMS	576	8232	5924	6084	5676	16636	
COL. CHI SUMS	105.097	580.806	79.530	57.567	66.516	502.215	

TOTAL SUM =43128.   DEGREES OF FREEDOM = 40   CHI SQUARED = .139173E 04

Strengths:

1. Data already processed; transformed; registered; rotated to north-south orientation.
2. Contains a band of classified data, thereby eliminating costly clustering procedures for user; makes relabeling of large areas easy, as user need only relabel a subsample of each vegetation class, rather than resample the entire ecozone.
3. Available at low cost.
4. Coverage includes the entire State of California.
5. Comes with tabular statistical summaries of the raw and classified data.

Limitations:

1. Vegetation labels very broad, due to clustering by ecozone; the more closely the study area corresponds to ecozone size the better.
2. Misregistration of bands possible; data also contains a few "seams" where Landsat scenes were inadequately mosaicked.
3. Data are Landsat 1 from August 1976, and cannot be updated without building a new data set; also, August date may not be optimal for intended use.
4. Because agriculture, urban areas, and clouds were not masked prior to the application of the clustering algorithm, the classified data contains some classes that the user might find extraneous.

General recommendations:

If the interested user has limited funding and a relatively large study area (i.e., greater than 50,000 acres), the CDF spectral data set is worth considering. The fact that the data are four years old may not matter for most wildland applications, as vegetation changes in those areas are more gradual. If updating is required (to keep track of fuel modification, timber removal, etc.), the alternative is to purchase Landsat scenes directly from EROS Data Center. Such scenes, though not mosaicked, will have accurate multiband registration. The classified data available with the CDF data set are a real advantage to the user interested in large areas, as the gross classes will not be a problem. If the user picks an adequate subsample of observation points within each class, he will be able to alter or refine the class labels for each ecozone by relabeling only his subset. The data also come with tabular summaries of the means and standard deviations between bands and vegetation classes, as well as scatterplots of the clustered data.

5.2 The DTT Data Set

The DTT data set proved to be wholly inappropriate for the Grapevine area, for reasons fully described above in Section 4. It is important to emphasize, however, that these data may be more than adequate in most parts of the United States where topographic relief is more moderate than in the California Coast Range. Some considerations concerning the use of this data set are listed below.

Strengths:

1. Low cost: $30 for the first 1° x 1° quadrangle, $15 for additional quadrangles.
2. As coverage is by 1° x 1° quadrangle, it is very inexpensive to acquire data for large areas.
3. Available for the entire United States.
4. Easily used, as one can extract areas of interest by simply measuring in .01" increments from the quadrangle corner.

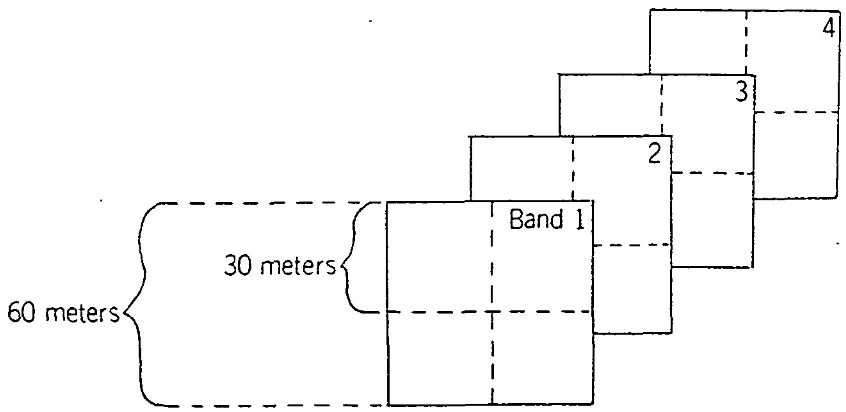
Limitations:

1. The USGS does not guarantee accuracy of its 1:250,000-scale topographic series, from which the DTT data were digitized; hence, the accuracy of the DTT data is uncertain.
2. The 200-foot elevation contours, and interpolation algorithm used during digitization, provide gross generalization of topographic relief.
3. Horizontal geographic control is poor, so it is difficult to confidently locate accurate control points even after data are registered to a geographic coordinate system.
4. West located at the top, so data must be rotated.

The advantage obtained by use of the DEM data should be considered in light of the data's drawbacks, however. The cost of the DEM data may preclude their use in large areas, as the costs run between $400 and $600 per $7\frac{1}{2}$-minute quadrangle, depending on the level of accuracy desired. If the quadrangle has already been processed, the cost drops to between $15 and $30 per quadrangle, or essentially the price of the magnetic tape to which the data are written. If a mile overlap is desired in order to facilitate mosaicking two quadrangles together, the cost is increased by $100.

Even if the DEM quadrangle has previously been processed, the user should be aware that the DTT's coverage ($1^{\circ} \times 1^{\circ}$) is equivalent to 16 DEM $7\frac{1}{2}$-minute quadrangles. Therefore, if the study area involves more than a few $7\frac{1}{2}$-minute sheets, the user may find it more affordable to go with DTT coverage.

A final consideration is that associated with in-house data handling costs. The DTT data's resolution is about 60-meters^2, as opposed to the DEM's 30-meter^2 resolution. Therefore, the DEM data requires four times the computer space per pixel per band, or 2^4 times as much space. (See diagram below.)



Obviously, computer costs will increase accordingly. For large areas, these costs could prove to be quite prohibitive.

In summary, both the DTT and DEM data have their attendent advantages and limitations. Table 13 briefly compares the two data sets.

Table 13. Comparative advantages/disadvantages associated with DEM and DTT data.

	Coverage	Resolution	Geographic Fidelity	Format	Costs Acquisition	In-house	Availability
DTT	$1^\circ \times 1^\circ$ Quadrangle	60-meter^2	Undefined	CCT	$30 for first quad; thereafter $15 apiece	60-meter^2 pixel size vs.	Immediate
DEM	$7\frac{1}{2}$-minute Quadrangle	30-meter^2	Excellent: RMS error 5-15 meters	CCT	$400 to $600 per quadrangle, depending on desired RMS error; if already processed, cost between $15 and $30	30-meter^2 pixel size, so 2^4 the cost of processing DTT	Immediate if quadrangle has been previously processed; several weeks for processing requests depending on current backlog requests at USGS

6.0 Future Activities

Now that the Grapevine data set has been constructed and analyzed, efforts are underway to utilize the data set for brush management work in the coordinated resource plan area. One example of this effort involves a 350-acre site within the plan area which is scheduled for chaining and brush removal later on this year. Using the Grapevine data set, RSRP personnel were able to provide the RCD with information concerning the range of slope, elevation, and aspect the field crew can expect to encounter. The data set also provided information about the vegetation types within the proposed site, as well as information related to the surrounding vegetation types.

7.0 Literature Cited

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APPENDIX A: Memorandum of Understanding

UNITED STATES
DEPARTMENT OF AGRICULTURE
Soil Conservation Service
Washington, D. C. 20250

UNITED STATES
DEPARTMENT OF AGRICULTURE
Forest Service
Washington, D. C. 20250

UNITED STATES
DEPARTMENT OF INTERIOR
Bureau of Land Management
Washington, D. C. 20240

I. PURPOSE

This Memorandum of Understanding, developed in consultation with the National Association of Conservation Districts, establishes policy and general guidelines for use by the Bureau of Land Management (BLM), Forest Service (FS), and Soil Conservation Service (SCS) for coordinating certain of their activities in resource planning and for working with Conservation Districts, State and Local agencies, private landowners who are conservation district cooperators, and other in developing and implementing sound resource management and conservation programs.

The May 19, 1971, agreement between BLM and SCS is hereby superseded.

II. POLICY

The Bureau of Land Management, Forest Service, and Soil Conservation Service will cooperate to the fullest degree possible in preparing and implementing resource management plans on operating units, allotments and other resource areas made up of intermingled or adjacent BLM and FS administered lands (hereinafter called public lands) and lands controlled by Conservation District (CD) cooperators (hereinafter called private lands).

The agencies cooperating on particular operating units or allotments will vary depending upon the landownership pattern within the planning area. The signatory agencies will seek to cooperate with all owners or managers of land and resources within each specific area -- including states, counties, or private owners. Other agencies and organizations will be involved as needed and appropriate.

III. AUTHORITY

BLM, FS, and SCS operate under separate legislative authorities and departmental policies including the following:

A. Soil Conservation Act, Public Law 46, 74th Congress, 1935, as amended, and Reorganization Plan No. IV, 1940, (16 U.S.C. 540a-f) and Comptroller General's Decision B-115665 (33C.G. 133), October 1, 1953.

B. The Taylor Grazing Act of June 28, 1934 (48 stat. 1269; 43 US Code 315 as amended).

C. National Environmental Policy Act of 1969, Public Law 91-190, 91st Congress, January 1, 1970.

D. Memorandum of Understanding between USDA and USDI dated April 20, 1942

E. Joint BLM-SCS Memorandum of April 10, 1964.

F. The Organic Act of June 4, 1897 (30 Stat. 35, as amended; 76 Stat. 1157; 16 U. S. C. 551)

G. The Multiple Use-Sustained Yield Act of June 12, 1960, (74 Stat. 215, 16 U. S. C. 528-531)

H. Title III, Bankhead-Jones Farm Tenant Act of July 22, 1937 (50 Stat. 525) as amended 76 Stat. 745), 7 U. S. C. 1010-1012.

I. Memorandum of Understanding between the Forest Service and Bureau of Land Management dated October 26, 1966.

J. Wild Free-Roaming Horses and Burros Act - P.L. 92-195 (85 Stat. 649, 16 U. S. C. 1331-1340)

K. All other applicable statutes and regulations not specifically referred to above relating to BLM, FS, and SCS programs.

IV. RESPONSIBILITY

A. The BLM and FS plan and conduct multiple-use resource management and conservation programs on lands under their jurisdiction. FS also has responsibilities to demonstrate and promote sound grasslands agriculture and conservation practices on the National Grasslands and areas of which they are a part.

B. The SCS provides technical and financial assistance to conservation district cooperators and participants in USDA cost-share programs for planning and applying authorized conservation programs on privately controlled lands.

C. The Conservation Districts, which are legal subdivisions of state government, develop annual and long-range programs, secure and coordinate assistance from appropriate agencies and organization, encourage and enter into cooperative agreements to assist individuals, groups, and units of government in conservation planning and application, provide means for determining local attitudes and objectives, and serve as catalysts to develop and maintain local interests in and support for conservation and development of resources.

V. OBJECTIVES

The objectives of coordinated resource planning are:

A. To promote cooperation between agencies and individuals to improve management and compatible use of the resources for which each is responsible.

B. To implement resource management plans to achieve compatible resource uses based on sound ecological relationships for logical management areas such as operating units, grazing allotments, and subwatersheds.

C. To optimize a sustained flow of food, fibre, and other goods, services and benefits from such lands while at the same time protecting and enhancing environmental qualities.

VI. GENERAL CONSIDERATIONS

A. Interagency reimbursement will not be made for planning and application assistance done under this memorandum.

B. BLM and FS will contact users of the public lands that are included in planning areas under their jurisdictions, and will retain responsibility for meeting all requirements of the laws and regulations pertaining to the use and management of these lands.

C. Cooperator contacts and followup assistance will normally be made by the agency having primary planning responsibility or will be mutually agreed upon before the onset of planning.

D. When any practices, structures, or projects are to be applied to or installed upon public lands under the jurisdiction of the BLM or FS, authorization must be obtained from the appropriate agency prior to initiation of the action.

E. The priorities and management objectives for BLM and FS administered lands will be determined through the responsible agency's planning system. However, special consideration normally will be given to resource areas presenting opportunities for coordinated resource planning.

F. Conservation districts will be encouraged to have memoranda of understanding with BLM, FS and/or other appropriate public land agencies at the local level.

G. When requested by the administering agency, SCS may provide technical assistance on public land intermingled or adjacent to private lands covered by a resource management plan when results benefit the private land.

H. Where State and private forests and related lands are involved the Forest Service will discharge its responsibilities through the appropriate State organization.

VII. STATE COORDINATION

A. STATE EXECUTIVE GROUP - The State Director (BLM), State Conservationist (SCS), and Regional Forester and/or Area Director (FS) will comprise this group. The chairman, State Conservation Commission, Committee, or Board, as appropriate, will be invited and encouraged to become a member. This group will develop and put into effect supplemental agreements, as needed, to meet the objectives of this memorandum, including procedure for specific programs to achieve agency coordination and cooperation throughout the State. They will meet annually to review progress, outline a course of action with appropriate followup, and otherwise facilitate coordination of agency procedures and programs. Representatives of the State Association of CD's and other appropriate State and Federal agencies such as State land, forestry, and wildlife agencies will be invited to participate in this meeting.

B. STATE TASK GROUP - This group will follow through with implementation of coordinated planning in the state. It shall be small in number but include representatives of major land and resource agencies including BLM, SCS, FS, and appropriate state agencies.

C. Conservation District Meetings - When invited by the CD, the BLM, SCS, and FS, as appropriate, will present reviews of proposed resource activities of concern to the District. Other agencies involved in the coordinated approach will be encouraged to do the same. The CD's will be encouraged to give due consideration to such activities when developing long-range programs and assigning priorities and work schedules for inclusion in their annual work plan.

VIII. INITIATING, PLANNING AND SCHEDULING

A. Initiation - The State Executive Group will arrange to acquaint field personnel with this memorandum to assure mutual understanding and interpretation.

B. Planning - Active participation by all key participants, from inception to completion of the planning process, is essential. The planning team should include representatives from all landowners and resource administering agencies within the operating unit, allotment, or resource area. A team leader should be designated for each planning unit considering such items as landownership pattern, location of the area, time and manpower needs and resources involved. Where full-time agency participation is not warranted, suitable review of the arrangements should be made at the local level so interagency coordinated planning can proceed with reasonable assurance that the final plan will be acceptable to all.

C. SCHEDULING - Each agency and group has its own program of activities for which priorities are established. Coordinated resource planning should be made to dovetail with each agency's activity schedule. This requires a reasonable amount of give-and-take between agencies and with conservation districts in the selection and assignment of priority to requests for coordinated plans. The State Executive Group will jointly prepare guidelines useful at the county and local levels in determining priorities, assigning responsibilities, and scheduling needed assistance.

IX. MODIFICATION

This agreement shall remain in effect until modified by the parties in writing; and is renegotiable at the option of any one of the parties.

ENDORSEMENT | APPROVALS

George R. Brodie 1/21/75
President, National Association of Conservation Districts

Curt Berklund JAN 15 1975
Director, Bureau of Land Management

Kenneth E. Grant
Administrator, Soil Conservation Service
JAN 10 1975

R. A. Keeler JAN 14 1975
for Chief, Forest Service

APPENDIX B: Coordinate Transformation Procedure for Establishing Geographic Control

The following steps were used to transform the spectral and terrain data to a common coordinate grid. This process basically involves the determination and application of regression coefficients to predict point and line coordinates.

B.1.1 Spectral Data

Select control points. Control points were located on 7½-minute orthophoto map* sheets for the Grapevine study area; in all, three orthophoto map sheets were required to cover the entire area. These control points had to correspond to features that could be accurately located on both the orthophoto map sheet and the spectral CDF image as displayed on the RSRP color monitor. This restriction limited the number of control points that could be located because, in this region of considerable topographic dissection, the ridges could not be accurately represented by the spectral data due to the large pixel size of the CDF data (80-meters^2). In all, 52 control points were initially selected.

Calculate regression coefficients. Coordinate transformation can be achieved on the RSRP computer system by either (a) rotation and scale correction of the data to a UTM grid, or (b) linear transformation based on regression coefficients. The RSRP personnel generally use the latter for coordinate transformation, as this method tends to simulate map projections more accurately within small geographic areas. Four regression models were tested with the set of 52 control points using a linear least-squares curve fitting program described by Daniel (1977). The four models are listed in Table B1(a). A series of iterations was performed on the data points in order to screen those points whose residuals (i.e., the difference between the observed and the predicted values for the same point) were deemed excessive. If the residuals were excessive (i.e., greater than two pixels), the point was rechecked on the color monitor and on the orthophoto map sheet in order to determine if a simple measurement error was the cause for the difference. This screening process

*Orthophoto map: a black-and-white photograph in which image displacement from camera tilt and terrain relief have been removed by simple or differential rectification.

Table B1a. The four regression models that were tested for the prediction of ground coordinates from CDF data set coordinates, and of CDF data set coordinates from ground coordinates.

Eq. 1. CDF coordinate $= a + b_1[UTM_{east}] + b_2[UTM_{north}]$

UTM coordinate $= a + b_1[CDF_{point}] + b_2[CDF_{line}]$

Eq. 2. CDF coordinate $= a + b_1[UTM_{east}] + b_2[UTM_{north}] + b_3[UTM_{east}][UTM_{north}]$

UTM coordinate $= a + b_1[CDF_{point}] + b_2[CDF_{line}] + b_3[CDF_{point}][CDF_{line}]$

Eq. 3. CDF coordinate $= a + b_1[UTM_{east}] + b_2[UTM_{north}] + b_3[UTM_{east}]^2 + b_4[UTM_{north}]^2$

UTM coordinate $= a + b_1[CDF_{point}] + b_2[CDF_{line}] + b_3[CDF_{point}]^2 + b_4[CDF_{line}]^2$

Eq. 4. CDF coordinate $= a + b_1[UTM_{east}] + b_2[UTM_{north}] + b_3[UTM_{east}]^2 + b_4[UTM_{north}]^2 + b_5[UTM_{east}][UTM_{north}]$

UTM coordinate $= a + b_1[CDF_{point}] + b_2[CDF_{line}] + b_3[CDF_{point}]^2 + b_4[CDF_{line}]^2 + b_5[CDF_{point}][CDF_{line}]$

Table B1b. The regression models that were used for the prediction of ground coordinates from DTT data set coordinates, and of UTM data set coordinates from ground coordinates.

Eq. 1. DTT coordinate $= a + b_1[UTM_{east}] + b_2[UTM_{north}] + b_3[UTM_{east}][UTM_{north}]$

UTM coordinate $= a + b_1[DTT_{point}] + b_2[DTT_{line}] + b_3[DTT_{point}][DTT_{line}]$

went through several iterations until the analyst was confident that all measurement errors had been corrected, and that any residuals present were due to the geometric properties of the Lambert Conic Conformal projection to which the CDF data set was mapped.

Based on their respective residuals and root mean square (RMS) errors, Equation 4 was chosen as the optimum model for predicting both CDF point-UTM east and CDF line-UTM north. The actual regression fits for CDF point and line are given in Table B2.

B.2.2 Terrain Data

Select control points. Establishment of horizontal geographic control of the DTT data had to be conducted differently than the procedure for the spectral data outlined above. Although the DTT data were initially digitized off a 1:250,000-scale USGS topographic quadrangle, the projection upon which the map was based contains inherent distortion. In order to account for that distortion, the four coordinate pairs representing the corner points of the 1° quadrangle were used *in lieu* of visually-located internal control points. These four coordinate pairs were supplied with the DTT, and were the most accurate points upon which to establish a set of regression coefficients between map bases.

Calculate regression coefficients. The linear least-squares regression algorithm was performed on the DTT data, using the four coordinate pairs. The number of regression models that could be tested was limited, as there were only four control points. The equations used to predict DTT point-UTM east and DTT line-UTM north are listed in Table B1(b). Table B3 lists the actual regression fits for DTT point and line.

Because only four observations were used to calculate the three regression coefficients, the resulting prediction equation provided an exact fit between observed and predicted values. Therefore, in order to provide a check on the validity of the prediction equation, the expected center coordinates of the 1° quadrangle, based on analytic geometry, were calculated in terms of DTT units and UTM meters. The expected UTM east and north coordinates of the center point were

Table B2. Regression fits for CDF point and line using UTM east and north as independent variables.

REGRESSION FIT FOR CDF POINT USING UTM EAST AND NORTH AS INDEPENDENT VARIABLES

Prediction equation:

$$CDF_{point} = 5462.0 \text{ meters} - .132363[UTM_{east}] + .0182667[UTM_{north}] + 1.929E7[UTM_{east}]^2 - 1.51523E6[UTM_{north}]^2 - 5.74374E7[UTM_{north}][UTM_{east}]$$

Analysis of Variance

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F-Value
Regression	2.272E5	5	4.544E4	1.654E5
Residual (error)	1.044E1	38	2.747E-1	
TOTAL	2.272E5	N-1=43		

Range of residuals: -.751 points -to- +1.013 points

Root mean square error: .5242 points

REGRESSION FIT FOR CDF LINE USING UTM EAST AND NORTH AS INDEPENDENT VARIABLES

Prediction equation:

$$CDF_{line} = 1327.32 \text{ meters} - 4.93507E\text{-}2[UTM_{east}] + 9.43599E\text{-}2[UTM_{north}] + 4.4746E\text{-}7[UTM_{east}]^2 + 8.67168E\text{-}7[UTM_{north}]^2 + 5.57759E7[UTM_{north}][UTM_{east}]$$

Analysis of Variance

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F-Value
Regression	6.180E4	5	1.236E4	6.884E4
Residual (error)	6.823	38	1.795E-1	
TOTAL	6.180E4	N-1=43		

Range of residuals: -.969 points -to- +.750 points

Root mean square error: .4237 lines

subsequently input into the prediction equations (Table B3). The predicted DTT point and line coordinates were then compared with the DTT point and line coordinates as calculated using analytic geometry. As can be seen in Table B4, the differences between the predicted and the calculated DTT points and lines were within a fraction of the 63-meter pixel size of the DTT data. Based on the results of this check, it was concluded that the regression equations listed in Table B3 would provide good registration between the DTT data and the UTM geographic base.

Table B3. Regression fits for DTT point and line, using UTM east and north as independent variables.

REGRESSION FIT FOR DTT POINT USING UTM EAST AND NORTH AS INDEPENDENT VARIABLES

Prediction equation: $DTT_{point} = -68201.5 + 4.972E\text{-}4[UTM_{north}] + 1.580E\text{-}1[UTM_{east}] - 9.377E\text{-}11[UTM_{north}][UTM_{east}]$

REGRESSION FIT FOR DTT LINE USING UTM EAST AND NORTH AS INDEPENDENT VARIABLES

Prediction equation: $DTT_{line} = -7815.29 + 1.573E\text{-}2[UTM_{north}] - 4.003E\text{-}6[UTM_{east}] + 8.005E\text{-}12[UTM_{north}][UTM_{east}]$

Table B4. Comparison between the use of regression coefficients versus the use of analytic geometry for estimating the center points of the UTM and DTT 1° quadrangles. The predicted coordinate pairs (px and py, derived from regression coefficients) and the expected coordinate pairs (ex and ey, derived form analytic geometry) for each respective data quadrangle differ by less than one pixel (63 meters).

PREDICTED

$$UTM_{coordinate} = a + b_1[DTT_{point}] + b_2[DTT_{line}] + b_3[DTT_{point}][DTT_{line}]$$

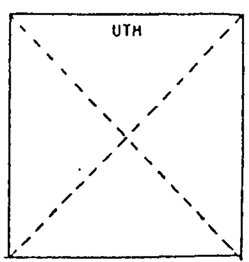
$$DTT_{coordinate} = a + b_1[UTM_{east}] + b_2[UTM_{north}] + b_3[UTM_{east}][UTM_{north}]$$

EXPECTED

$$\frac{Y_c - Y_{northwest}}{Y_{southeast} - Y_{northwest}} = \frac{X_c - X_{northwest}}{X_{southeast} - X_{northwest}}$$

$$\frac{Y_c - Y_{southwest}}{Y_{northeast} - Y_{southwest}} = \frac{X_c - X_{southwest}}{X_{northeast} - Y_{southwest}}$$

500000,4427590 585310,4427590



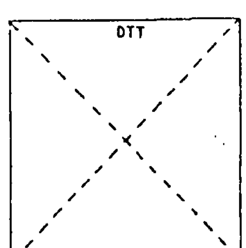
500000,4316570 586520,4316570

$UTM_{px} = 4.96828E5 + 6.34312E1[727.39] + 1.02281E-4[934.38] + -2.04562E-6[727.39][934.38]$

$UTM_{py} = 4.31341E6 + -3.73686E-1[727.39] + 6.34751E1[934.38] + 2.39903E-5[727.39][934.38]$

UTM_{px} = 542955.5	UTM_{ex} = 542965.93	Difference = 10.43 meters
UTM_{py} = 4372470.0	UTM_{ey} = 4372464.35	Difference = 5.65 meters

50,1799 1395,1806



50,50 1414,58

$DTT_{px} = -7.81529E3 + 1.57306E-2[542955.5] + -4.00273E-6[4372470.0] + 8.00546E-12[542955.5][4372470.0]$

$DTT_{py} = -6.82015E4 + 4.97234E-4[542955.5] + 1.58008E-2[4372470.0] + -9.37712E-11[542955.5][4372470.0]$

DTT_{px} = 727.229	DTT_{ex} = 934.382	Difference = .161 (10.22 meters)
DTT_{py} = 727.390	DTT_{ey} = 934.384	Difference = .002 (.14 meters)

APPENDIX C: Labeling Procedure

The steps required to relabel the CDF clusters are outlined in the following paragraphs, and are graphically represented in the flow chart found in Figure C1.

C.1 Generate Ancillary Spectral Data

As an interpretation aid, three types of ancillary spectral values were calculated using the CDF data: (1) mean Band 4/mean Band 2 ratio; (2) mean Band 1/mean Band 2 ratio; and (3) Euclidean brightness (EB). Based on a cluster's relative ranking to other clusters in one or more of these data types, plus the original CDF label, the image analyst was able to set her expectations as to the probable brush management label that could be assigned to that cluster. The mean brightness values from which these ancillary data were calculated are given in Table C1; the ranked clusters and ancillary data are given in Table C2.

The ratio of the mean of Band 4 (far reflectance infrared) to the mean of Band 2 (red) is an indicator of general vegetation condition. The ratio contains most of the spectral information regarding vegetation development while tending to normalize the influence of such confounding factors as solar radiation and topography (Nalepka, *et al.*, 1977). This ratio is also valuable for establishing the "soil line". Generally speaking, 4/2 ratios that are greater than 1.09 (the "soil line") indicate the presence of vegetation, while ratios below 1.09 indicate bare soil, water, snow, and other nonvegetated surfaces.

The ratio of the mean of Band 1 (green) to the mean of Band 2 (red) is an indicator of visual "yellow-greenness". This ratio is useful for labeling the annual grass classes which tend to have higher amounts of accumulated dried "yellow" vegetation along with green vegetation during and subsequent to senescence. This means that the 1/2 ratio tends to be lower for senescent grass classes than for other natural vegetation classes (Hay and Thomas, 1978).

The Euclidean brightness (EB) value is the sum of the Euclidean

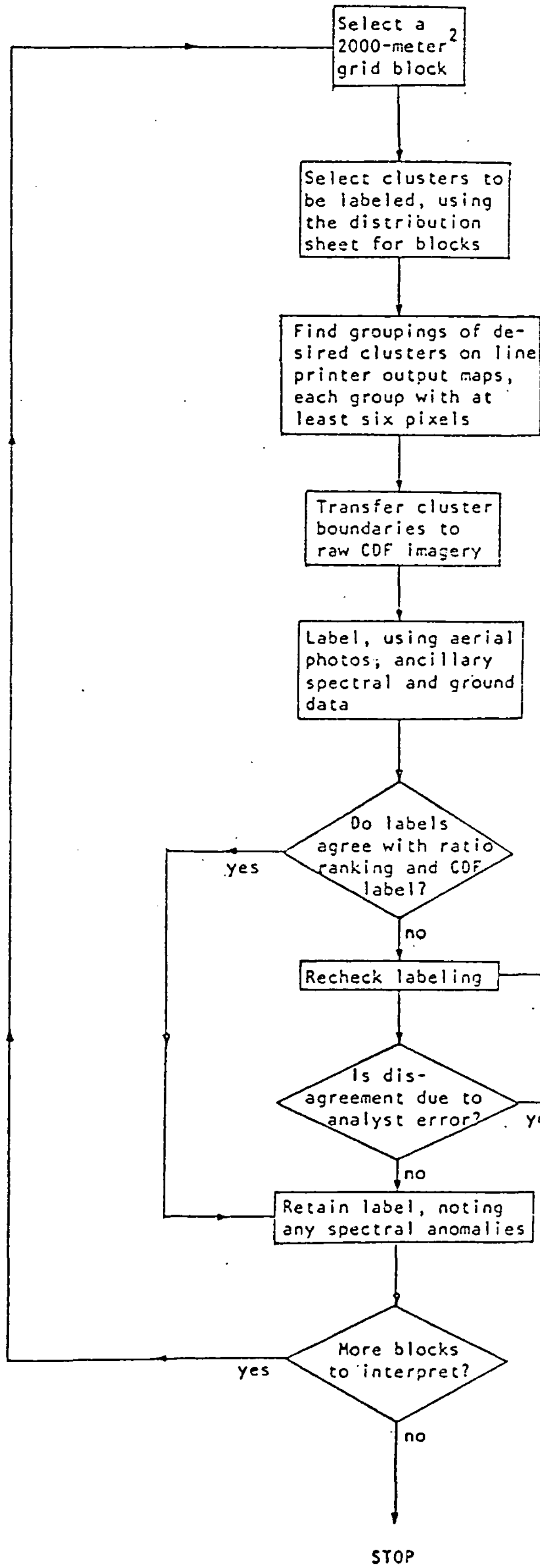


Figure C1. Stepwise procedure used to relabel the CDF clusters.

Table C1. Mean brightness values for the CDF clusters.

CDF DATA SET: NORTH CENTRAL INTERIOR ECOZONE

CLUSTER NUMBER	SYMBOL	BAND MEAN 1	2	3	4
58	1	23.38	12.66	6.93	2.54
59	2	19.37	12.89	13.50	10.82
60	3	21.39	16.60	21.30	19.68
61	4	19.88	14.58	18.07	16.02
62	5	22.62	18.96	17.40	13.61
63	6	17.04	10.03	17.82	17.49
64	7	17.97	11.04	21.61	22.38
65	8	23.87	21.68	21.45	18.15
66	9	20.92	15.58	24.34	24.33
67	A	18.93	11.93	27.88	30.54
68	B	23.31	19.62	24.18	22.37
69	C	19.30	13.03	25.64	26.99
70	D	21.24	15.70	29.42	31.39
71	E	26.46	24.95	24.90	21.45
72	F	19.57	13.04	30.89	34.44
73	G	23.86	19.99	29.62	30.03
74	H	24.53	21.40	26.80	25.08
75	I	21.04	14.95	34.41	38.68
76	J	26.59	24.58	28.51	26.30
77	K	22.67	17.81	31.95	34.44
78	L	28.57	27.72	29.10	25.86
79	M	20.74	14.05	38.35	44.31
80	N	25.84	22.61	34.97	36.60
81	O	26.14	21.62	40.25	43.37
82	P	27.85	26.67	31.49	30.14
83	Q	30.08	29.95	32.34	29.85
84	R	30.95	30.97	30.54	25.96
85	S	23.89	16.52	46.19	53.83
86	T	28.68	27.16	34.31	33.82
87	U	31.75	32.14	35.71	33.51
88	V	32.87	33.72	33.30	28.76
89	W	30.71	29.84	39.39	38.72
90	X	36.25	30.09	40.80	36.12
91	Y	34.85	36.57	36.60	31.76
92	Z	41.70	47.91	46.98	41.04

Table C2. Ancillary spectral data for the Grapevine study area.

NORTH CENTRAL INTERIOR ECOZONE

RANK	4/2 RATIO MAP SYMBOL	4/2 RATIO CDF LABEL	4/2 RATIO VALUE	1/2 RATIO MAP SYMBOL	1/2 RATIO CDF LABEL	1/2 RATIO VALUE	EUCLIDEAN BRIGHTNESS $(1^2+2^2+3^2+4^2)^{\frac{1}{2}}$ MAP SYMBOL	EUCLIDEAN BRIGHTNESS CDF LABEL	EUCLIDEAN BRIGHTNESS VALUE
1	S	agriculture	3.258	1	water	1.847	Z	barren	89.026
2	M	hardwood	3.154	6	hardwood conifer	1.699	S	agriculture	76.647
3	F	conifer woodland	2.641	7	hardwood conifer	1.619	X	barren	76.232
4	I	hardwood	2.587	A	hardwood conifer	1.570	Y	barren	70.001
5	A	hardwood conifer	2.560	2	brush	1.503	W	grass	69.888
6	C	hardwood conifer	2.071	F	conifer woodland	1.501	O	grass	68.204
7	7	hardwood conifer	2.027	C	hardwood conifer	1.481	U	grass	66.627
8	O	agriculture	2.006	M	hardwood	1.476	V	grass	64.448
9	D	hardwood	1.999	S	agriculture	1.446	M	hardwood	63.731
10	K	hard-woodland	1.934	I	hardwood	1.407	T	grass	62.299
11	6	hardwood conifer	1.744	4	brush	1.364	N	grass	61.167
12	N	grass	1.619	D	hardwood	1.353	Q	grass	61.145
13	9	brush	1.562	9	brush	1.343	R	grass	59.360
14	G	brush	1.502	3	hard-woodland	1.289	P	grass	58.015
15	W	grass	1.298	K	hard-woodland	1.273	I	hardwood	57.848
16	T	grass	1.245	O	grass	1.209	L	grass	55.679
17	3	hard-woodland	1.186	G	brush	1.194	K	hard-woodland	55.118
18	H	hard-woodland	1.172	5	brush	1.193	J	hard-woodland	53.063
19	P	grass	1.147	B	hard-woodland	1.188	G	brush	52.422
20	B	hard-woodland	1.140	H	hard-woodland	1.146	F	conifer woodland	51.897
21	4	brush	1.099	N	grass	1.143	D	hardwood	50.483
22	J	hard-woodland	1.070	8	hard-woodland	1.101	H	hard-woodland	49.060
23	U	grass	1.043	J	hard-woodland	1.082	E	hard-woodland	49.018
24	Q	grass	.997	E	hard-woodland	1.061	A	hardwood conifer	46.937
25	L	grass	.933	P	grass	1.060	B	hard-woodland	44.860
26	X	barren	.924	T	grass	1.056	C	hardwood conifer	43.911
27	Y	barren	.868	L	grass	1.031	9	brush	43.183
28	E	hard-woodland	.860	W	grass	1.029	8	hard-woodland	42.771
29	Z	barren	.857	Q	grass	1.004	3	hard-woodland	39.675
30	V	grass	.853	R	grass	.999	7	hardwood conifer	37.538
31	2	brush	.839	U	grass	.988	5	brush	36.866
32	R	grass	.838	V	grass	.975	4	brush	34.510
33	8	hard-woodland	.837	Y	barren	.953	6	hardwood conifer	31.850
34	5	brush	.178	X	barren	.927	2	brush	28.994
35	1	water	.201	Z	barren	.870	1	water	27.593

distances between the band means, and is calculated as follows:

$$EB = [(\text{mean Band 1})^2 + (\text{mean Band 2})^2 + (\text{mean Band 3})^2 + \text{mean Band 4})^2]^{\frac{1}{2}}$$

This value is a measure of the cluster's albedo, and is useful for making distinctions between brush subclasses (i.e., manzanita and chamise).

It is significant that the relative rankings of the clusters within each ancillary data set are more important than the critical analysis of the ancillary data values that have been calculated for each spectral cluster. The actual values associated with vegetation types will vary among geographic regions of California. (See Benson and Beck, 1979, for an example of how an image analyst might use these ancillary data in a labeling procedure.)

C.2 Label Clusters by Block

In order to facilitate the interpretation of clusters, a line printer map showing the distribution of the spectral clusters was produced for each 2000-meter^2 grid block. An example of this type of output is shown in Figure C2. These cluster maps were used by the image analyst to visually determine the location of clusters on the raw CDF data, and subsequently on the color infrared U-2 imagery. Line printer maps were considered superior to color-coded photographic products because (1) they could be reproduced inexpensively, and (2) the alpha-numeric characters were found to be unambiguous identifiers for each of the 35 potential clusters in each 2000-meter^2 block.

The following three values were calculated for each cluster in order to aid in interpretation: (1) the pixel count present in each 2000-meter^2 block; (2) the percent of the block that the cluster represented; and (3) the percent of the cluster sample total that was represented in the 2000-meter^2 block.

Select spectral sample block.

The pertinent U-2 photography, orthophoto map sheets, and ancillary data were assembled, and the 2000-meter^2 grid was overlaid on the

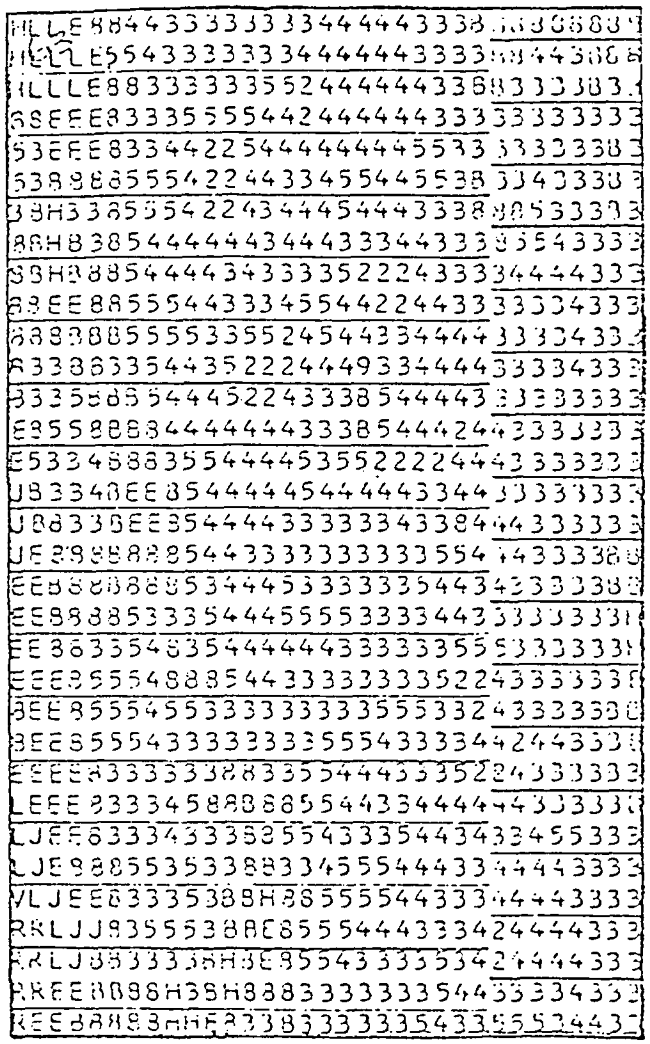


Figure C2. Line printer map showing the distribution of spectral clusters in Block 63. This area, as imaged on raw CDF data, orthophoto map sheets, and U-2 aerial photography, is shown in Figure C3a, b, and c, respectively.

U-2 photography and the orthophoto sheets. The CDF spectral image for Block 63 and associated ancillary image products are shown in Figure C3.

Select clusters to be labeled.

By referring to the line printer maps and their associated spectral counts, the analyst determined which classes were best represented within the selected block. To facilitate the choice, a master sheet was compiled for each cluster on which was listed the blocks in which the largest population of each cluster could be found (Table C3). If the selected block contained a relatively large proportion of a certain cluster, the analyst made sure that she labeled that cluster in the block.

Locate groupings of desired clusters on line printer maps.

Large groupings of spectral clusters were outlined on the line printer output. Each cluster group consisted of at least six pixels. Considering the large number of clusters that were normally represented in a block, the line printer output was superior to color-coded photographic products in that it was easier to differentiate groupings of symbols than to locate groupings of subtle colors.

Transfer cluster group boundaries to raw CDF imagery.

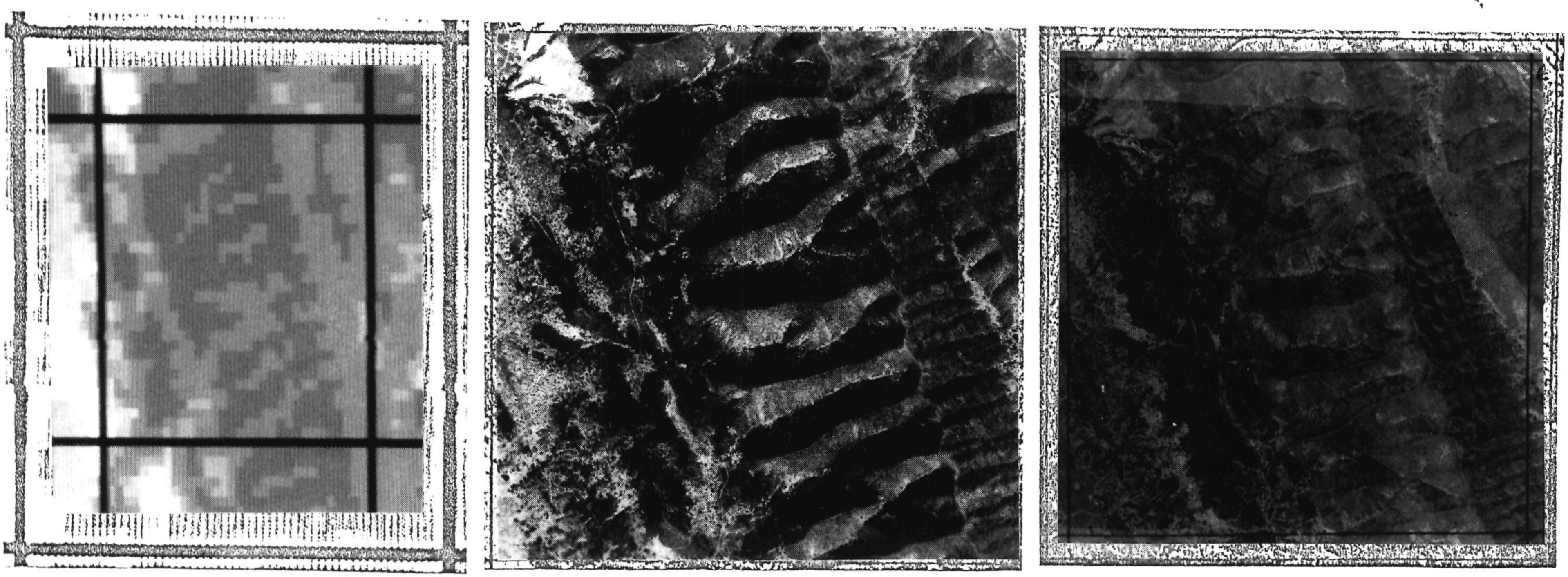
The analyst transferred the cluster outlines to either a photo of the raw CDF image or to the interactive color display monitor. The annotated image was used as a visual link between the line printer output, the U-2 photography and the orthophoto map sheet.

Label clusters in block.

Each cluster group was located and identified on the U-2 imagery. The ancillary data, e.g., the orthophoto coverage, the 4/2 ratio, the 1/2 ratio, EB, and CDF labels, assisted in this labeling process by helping the analyst set her expectations as to the most probable label. In some cases, the analyst had access to ground data and personal knowledge of the sample block area.

Check labels against the ratio rankings and the original CDF labels.

If the brush management labels were in general agreement with those of the CDF, the analyst then proceeded to another block. If there was



a b c

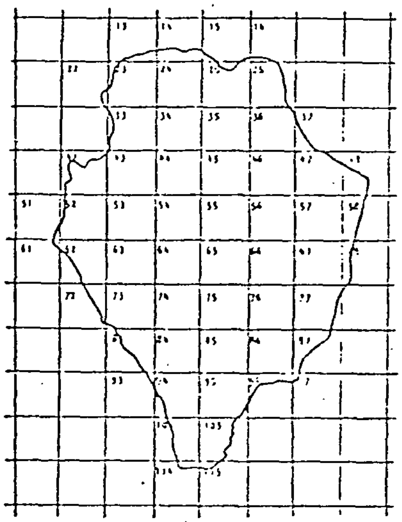
Figure C3. Graphic products used to relabel spectral clusters in Block 63.

(a) Raw CDF spectral image, 2000 meters-by-2000 meters.

(b) Orthophoto coverage, 2000 meters-by-2000 meters.

(c) U-2 photography, 2000 meters-by-2000 meters.

Table C3. Master chart showing cluster populations per 2000-meter^2 block in the Grapevine study area.



COF DATA SET: NORTH CENTRAL INTERIOR ECOZONE

BLOCK NUMBER	CLUSTER NUMBER (SYMBOL) 59(2)	60(3)	61(4)	62(5)	65(8)	66(9)	68(B)	71(E)	73(G)	74(H)
13		32	9	18	20		22	19		11
14		18			13		36	25		63
15								1		1
16							2			
22									1	4
23	15	173	57	111	179		195	83		100
24	1	69	6	17	116		272	133		172
25	1	36	17	29	83		38	104	6	42
26					9		9	70		23
33	24	176	115	81	133		87	99		55
34		242	3	18	120		328	45		153
35	12	144	70	69	64	2	95	62		143
36					24		18	85	5	53
37								8		3
42	1	127	57	41	103		44	65		50
43	39	261	139	102	221		127	54		61
44	11	322	75	53	139		361	18		92
45	4	207	39	62	103	1	158	44	20	108
46		59	12	4	57		74	93	5	55
47					8			32		1
48										
51										
52	6	56	38	68	110		20	160		8
53	30	429	312	100	69		109	16	1	25
54	19	324	164	62	73	6	276	26	6	130
55	5	319	49	57	103		217	58	2	197
56		40	8	5	21	2	54	67	32	97
57					4		4	26	3	17
58										
61										
62		4	1	3	14		14	55		9
63	32	416	243	131	105	1	68	48		14
64	85	301	170	107	72	4	217	13		104
65	2	338	27	25	81	1	284	63	3	117
66	5	72	27	24	62	2	72	81	22	109
67							2	26		12
68										
72								4		1
73	34	169	235	97	127		35	85		17
74	15	362	323	57	44		83	18		23
75		246	39	15	84	7	290	56	6	182
76		116	34	47	121	4	123	120	8	117
77								26	3	1
83		47	21	52	190		28	79		40
84	19	182	184	48	75	1	112	61	5	119
85	3	95	43	28	42		80	58	5	98
86		33	5	14	147		66	165		26
87					1		3	21		
93					1		1	10		5
94	4	142	68	51	75	1	100	56	19	94
95	2	22	5	25	45		55	72	8	64
96					6		5	24		3
97					1			2		1
104		16		7	50		44	82	12	32
105		27	10	20	52		35	67	3	47
114							1	3		1
115					1			6		

disagreement (e.g., CDF label "hardwood" versus analyst label "chamise"), the labels within the block were rechecked for possible analyst error. The most common sources for analyst error were: (1) inaccurate transfer of cluster group boundaries to the raw CDF image and subsequently to the aerial photography, and (2) improper interpretation of ground conditions from the supporting aerial photography and ancillary data. If, after rechecking the label, the analyst did not change the brush management label, the ambiguity between the labels was attributed to either (1) incorrect CDF labeling, (2) incompatibility between the definitions of the CDF and fuel management classes, or (3) spectral anomalies within the block.

C.3 Compare Cluster Labels for All Blocks.

Each cluster was labeled in at least five blocks in order to ascertain the cluster's integrity throughout the study area; that is, the cluster should have represented the same type and condition of vegetation regardless of location within each of the spectral blocks. If a cluster was consistently identified as a certain vegetation type, that label was assigned to the cluster, whether or not there was agreement with the original CDF label.

PART IV

MAPPING WILDLAND FUEL HAZARDS IN SHASTA COUNTY, CALIFORNIA

by

Andrew S. Benson

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS FOR THE SHASTA COUNTY STUDY

PART IV

MAPPING WILDLAND FUEL HAZARDS IN SHASTA COUNTY, CALIFORNIA

1.0 Introduction

In October 1979 the first meeting of the Shasta County Fuel Break Planning Committee was held in Redding, California. The membership of this committee was composed of interested persons from County, State, and Federal agencies, along with local advocacy groups and private citizens. The primary objective of this committee has been to develop and implement an agressive brush management program in eastern Shasta County. The expected benefits of such a program would be to reduce fuel loadings, increase water yield, increase livestock production, improve wildlife habitat, increase forest productivity, reduce soil erosion, and improve esthetic values.

The involvement of our RSRP personnel with the Shasta County Vegetation Management Committee (VMC) has been in an advisory capacity during the past 18 months. In this period we have developed a preliminary data bank covering the 196,000-acre study area (see Figure 1). The following sections briefly describe the results to date of this effort.

2.0 Results to Date

A digital data bank has been constructed for the VMC study site in Shasta County. (A complete description of the procedures used to construct this data bank is given in Part V.) The cell size of the grid used for the data bank is 63.5 meters by 63.5 meters (one acre). The primary components for this bank are (1) raw Landsat data from the statewide Landsat digital mosaic (see Part III for additional details about this digital mosaic), (2) a ten-class thematic map produced from (1) above, and (3) hypsographic data derived from the Defense Mapping Agency digital terrain data. A listing of the components comprising the data bank as it is now configured is given in Table 1.

A number of tabular and graphic output products have been made from this data bank and given to members of the VMC for their inspection. Examples of these products are given in Figure 2 and Table 2. Figure 2 includes the following items for the 196,000-acre study area: raw and

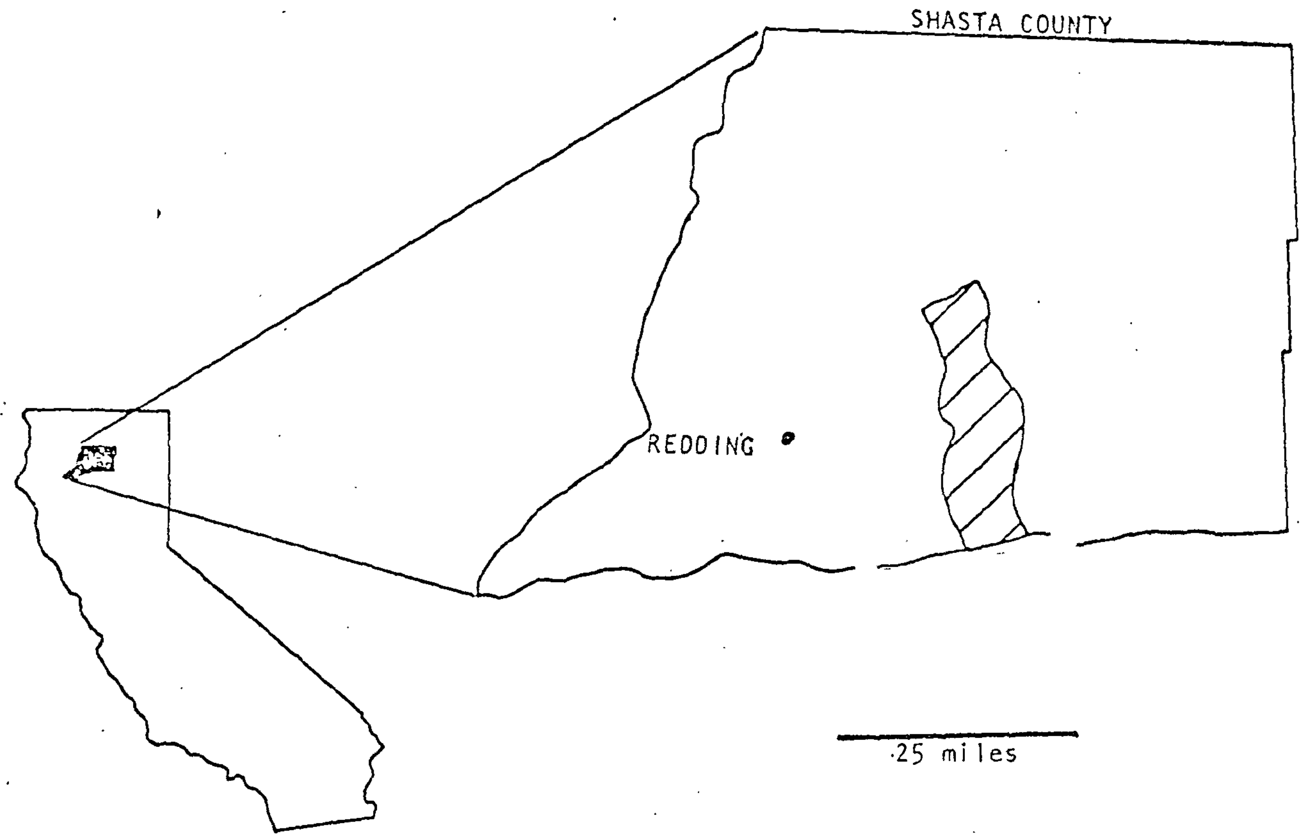


Figure 1. Location of the 196,000-acre vegetation management study site (cross-hatched area) in Shasta County, California. Personnel from the Remote Sensing Research Program, University of California, Berkeley, have been providing support to the County Vegetation Management Committee which is initiating aggressive fuel management actions in the central third of the County.

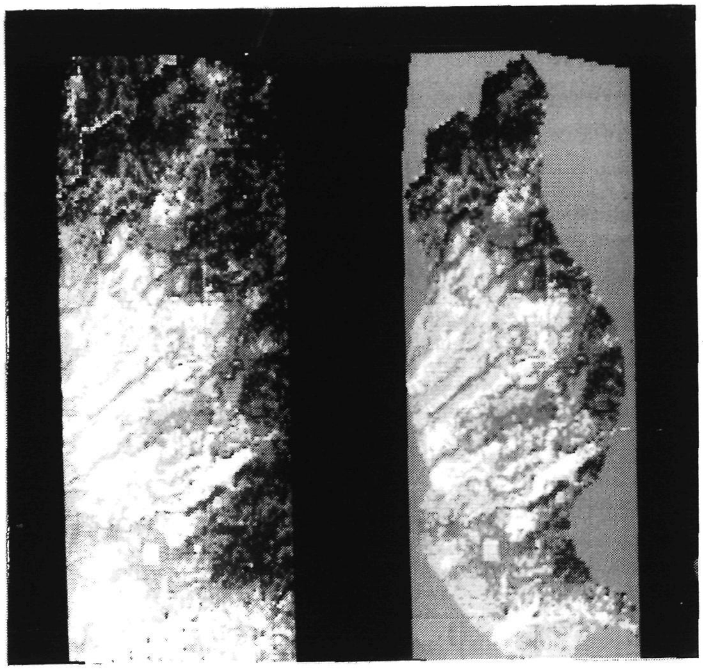
Band Number	Name	Source	Description
1	VMSS 4	CDF statewide Landsat mosaic, raw	Landsat MSS green, VICARS format
2	VMSS 5	CDF statewide Landsat mosaic, raw	Landsat MSS red, VICARS format
3	VMSS 6	CDF statewide Landsat mosaic, raw	Landsat MSS near reflectance infrared, VICARS format
4	VMSS 7	CDF statewide Landsat mosaic, raw	Landsat MSS for reflectance infrared, VICARS format
5	Slope 15	Defense Mapping Agency Digital Terrain Data	flat + 5% slope classes
6	Aspect 49	Defense Mapping Agency Digital Terrain Data	flat + 7.5° aspect interval
7	400FTCON	Defense Mapping Agency Digital Terrain Data	400-foot elevation zones
8	VEG12	CDF statewide Landsat mosaic, classified	12-class vegetation map
9	ASPECT 5	Defense Mapping Agency Digital Terrain Data	flat + 90° aspect interval
10	NFDRS	Defense Mapping Agency Digital Terrain Data	National Fire Danger Rating System slope classes

Table 1. Components comprising the digital data bank that has been constructed for the 196,000-acre Shasta County fuel management study area.

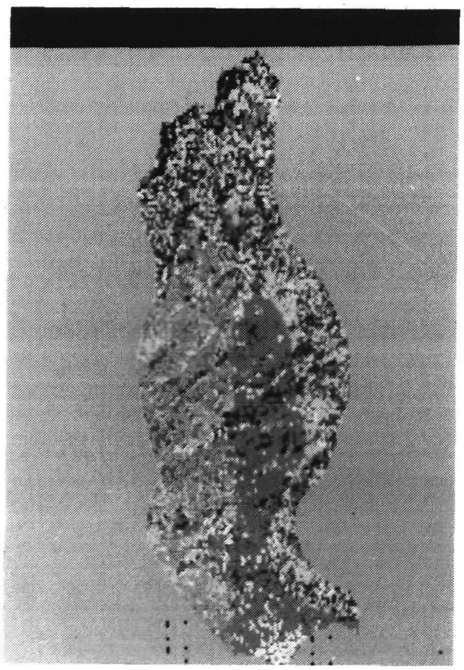
classified Landsat data, plus thematic maps of aspect, elevation, and slope. Table 2 provedes tabular information giving the distribution of the vegetation resources with respect to aspect and elevation. This type of information is useful if more detailed vegetation labels are needed. For example, the higher elevation conifer types may be labeled as ponderosa pine, while the lower elevation types may be labeled as digger pine.

3.0 Work to be Completed During 1981-1982

It is difficult to speculate on the extent of the work that will be conducted during this time period until the levels of Federal and State programs have been finally determined. At the very least, with the assistance of VMC personnel, we will try to refine the vegetation labels and to provide area summaries for smaller management units.



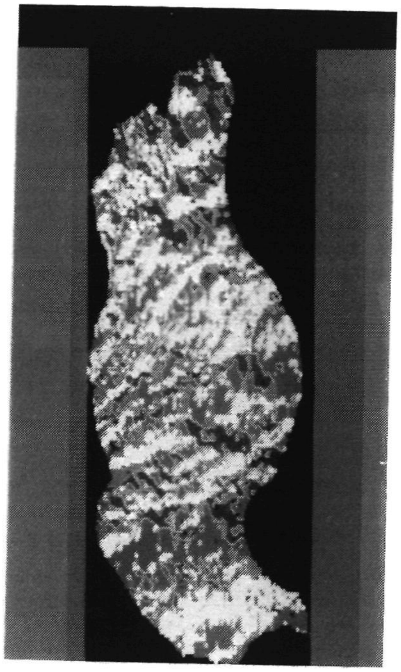
(a) Raw data:
Landsat MSS bands 4, 5 and 7
unmasked and masked



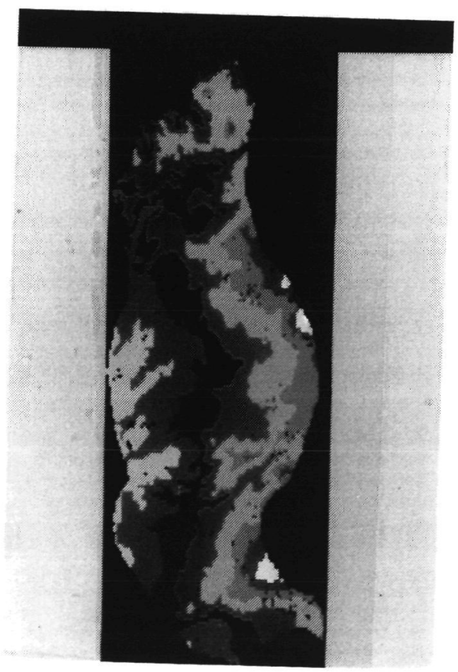
(b) Classified data:

dark blue	=	water
green	=	conifer
light green	=	brush
light blue	=	barren
olive green	=	conifer/woodland
brown	=	hardwood/woodland
yellow	=	grassland
red	=	hardwood
gold	=	open shrub

Figure 2. The 196,000-acre vegetation management study area in eastern Shasta County, Claifornia. These images are output products from the Landsat MSS component of a digital data bank that was constructed for the area and subsequently displayed on the RSRP interactive color monitor. For these figures, only every fourth picture element was displayed.



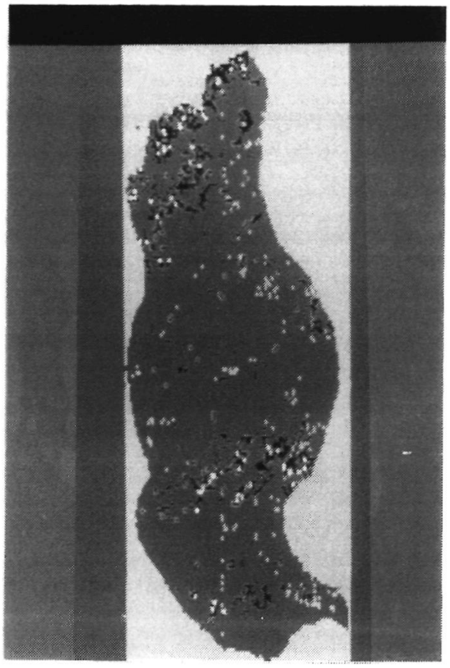
(c) Aspect:
blue = flat
green = north
violet = east
red = south
yellow = west



(d) Elevation above sea level:

blue-gray	=	600-1000 feet
violet	=	1000-1400 feet
green	=	1400-1800 feet
red	=	1800-2200 feet
yellow	=	2200-2600 feet
light green	=	3000-3400 feet
blue	=	3400-3800 feet
white	=	3800-4200 feet

Figure 2. (continued)



(e) National Fire Danger Rating System Slope Classes:
violet = 0-25%
blue = 26-40%
white = 40-55%

Figure 2. (concluded.)

CLASS	DISTRIBUTION (%) OF CLASS							ELEVATION (RANGE 600 FT. - 4200 FT.)				
	Number of Pixels	% of Total	Flat	North	East	South	West	Low	1st Qtr	Median	3rd Qtr	High
Water	239	<1	2	28	6	21	43	600	1200	1600	2000	2600
Conifer	10,186	5	8	30	12	19	31	600	1300	1700	2100	3800
Brush	53,776	28	10	16	5	31	37	600	1100	1500	1850	3400
Barren-Rock	5,734	3	11	22	5	20	43	600	1000	1200	1400	3000
Conifer/Woodland	6,417	3	7	29	7	21	37	800	1500	1900	2400	3800
Conifer/Hardwood	14,725	8	11	22	11	18	37	1000	1900	2300	2600	3200
Hardwood/Woodland	34,926	18	7	21	7	26	39	800	1700	1900	2300	4000
Grass	18,994	10	11	17	6	28	38	600	1100	1600	2000	2800
Hardwood/Conifer	23,938	12	9	18	9	30	35	600	1600	2100	2400	3200
Hardwood	15,425	8	15	17	8	27	32	600	800	1200	1600	2600
Shrub	9,835	5	16	17	8	25	35	600	1200	1650	2000	3600
	194,245											

Table 2. Distribution of the 11 resource classes within the Shasta County vegetation management study area with respect to aspect and elevation.

PART V

CONSTRUCTION AND PRELIMINARY ANALYSIS OF THE BIG BASIN STATE PARK DIGITAL DATA BANK

by

Andrew S. Benson

and

Paul R. Ritter

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LIST OF ILLUSTRATIONS FOR THE BIG BASIN STATE PARK DIGITAL DATA BANK STUDY

PART V

CONSTRUCTION AND PRELIMINARY ANALYSIS OF THE BIG BASIN STATE PARK DIGITAL DATA BANK

1.0 Introduction

During the past year, a multiband digital data bank has been constructed for Big Basin State Park, California by personnel from the Remote Sensing Research Program (RSRP), University of California, Berkeley, and Department of Botany, University of California, Santa Cruz, for the California Department of Parks and Recreation. The input components to this bank include Landsat spectral and classified data, hypsographic data, and soils data. The resulting bands have been evaluated using chi-square tests and an analysis of multidimensional histograms to determine whether systematic relationships exist among the bands. Based on the results of these tests, a single band has been used to represent the frame from which ground samples were allocated. The data collected from these ground samples will be used to quantify the distribution of the natural vegetation within the Park for predicting wildfire and prescribed fire behavior.

2.0 The Big Basin Digital Data Bank

2.1 General Description

The data bank structure used at the RSRP is a three-dimensional array. Each array entry, or cell, is referenced by a set of X, Y, and Z coordinates representing column, row, and band number respectively. An X-Y coordinate pair refers to the center of a cell and represents a square or rectangular area on the ground. A Z-coordinate, or band, contains coded information which represents a particular ground parameter, such as elevation or soil type, for every pair of X-Y coordinates.

Based on the ground sampling criteria and available data sources, the Big Basin data bank was designed to be aligned to the Universal Transverse Mercator grid system (UTM) and to have a ground cell size of 60-by-60 meters. The UTM grid system was selected because (1) it is present on most USGS map sheets, and (2) it is represented as a square on these maps. These characteristics allow easy conversion between the X-Y coordinate pairs of cells within the data bank and the corresponding UTM east and north coordinate pairs on the ground. The 60-by-60 meter cell size was selected because it closely matched the nominal cell size of the hypsographic input component.

2.2 Input Components to the Big Basin Data Bank

To date, four input components have been used to construct the Z-coordinates, or bands, of the Big Basin digital data bank: spectral and classified digital data from a statewide Landsat mosaic, digital terrain data, soil maps, and a boundary map.

2.2.1 The spectral and classified component represented a portion of the statewide Landsat-1 mosaic created by NASA at the Jet Propulsion Laboratory and the Ames Research Center, and by the California Department of Forestry (CDF). This data set, hereafter referred to as the CDF data set, was constructed from Landsat-1 scenes that were mosaicked together digitally, resampled to an 80-by-80 meter cell size, and mapped by 1°-by-1° quadrangles to a Lambert Conic Conformal projection and an orientation of N 13°E. The raw spectral bands included VMSS4[(1)] = green, VMSS5 = red, VMSS6 = near-reflectance infrared, and VMSS7 = far-reflectance infrared. The classified band consisted of 36 spectral ground condition types that resulted from an unsupervised classification of the four raw spectral bands. Each spectral class was assigned a ground condition label by CDF field personnel on a quadrangle-by-quadrangle basis. A complete description of the CDF data set cam be found in Bensón and Beck (1979).

A rectangle comprised of 550-by-450 CDF cells was extracted from the San Francisco West quadrangle. This rectangle encompassed the irregularly shaped Park and included a considerable area surrounding it.

2.2.2 The hypsographic component was a portion of the San Francisco West quadrangle of the U.S. Geological Service digital terrain data (DTT) set. These data represent the actual or interpolated elevation values for .01 inch (approximately 60 meters ground distance) on the USGS 1:250,000 quadrangles. These quadrangles, mapped to the UTM projection, are digitized in 1°-by-1° blocks with an orientation of N 90°W.

A rectangle of 250-by-300 cells was extracted from the San Francisco West quadrangle which encompassed the Park. The rectangle was rotated 90° to form a 300-by-250 cell rectangle with an orientation of north.

[1] VMSS refers to Landsat multispectral scanner data that have been reformatted on the VICARS (Video Information Communication and Retrieval) software system at the Jet Propulsion Laboratory.

2.2.3 The soil component was compiled from the relevant $7\frac{1}{2}$-minute soil series quadrangles for Santa Cruz County. These quadrangles were mapped to a polyconic projection. A composite of these quadrangles is shown in Figure 1.

2.2.4 The boundary component was visually transferred from an uncontrolled Department of Parks and Recreation visitor's map (projection unknown) to the $7\frac{1}{2}$-minute quadrangle (polyconic projection). The transfer procedure was accomplished easily because most of the Park boundaries coincided with section lines present on the quadrangles.

2.3 Transformation and Registration of Components to the Data Base

Because the four input components differed with respect to format, scale, and orientation, each was registered separately to the 60-by-60 meter UTM data base. The registration process was achieved through the application of specific regression coefficients to the coordinate pairs associated with each input component.

2.3.1 The regression coefficients applied to the Landsat component were determined from a set of 23 highly visible control points that appeared on both the raw CDF image (VMSS bands 4, 5, and 7) and the orthophoto map sheets of the area. The CDF image was displayed on the RSRP display system's color monitor, and the row and column number for each control point were recorded. These points were located on orthophoto map sheets, and the UTM east and north coordinates were measured. The general form of the regression equation used to develop the UTM-to-CDF coordinate transform was as follows:

$$CDF_{column} = a + b_1(UTM_{east}) + b_2(UTM_{north})$$

$$CDF_{row} = c + d_1(UTM_{east}) + d_2(UTM_{north})$$

A more complex regression form was not required because the data had been previously resampled to the 80-by-80 meter grid system.

Based on the regression coefficients developed above, the coordinate transformation program, "COTRAN," resampled the cells in the CDF data set to the UTM base. For each 60-by-60 meter cell in the UTM data base, COTRAN calculated the respective CDF row-column coordinate pair and transferred the data value for that cell to the UTM cell. All five bands of the CDF data set were registered to the UTM data base in this manner.

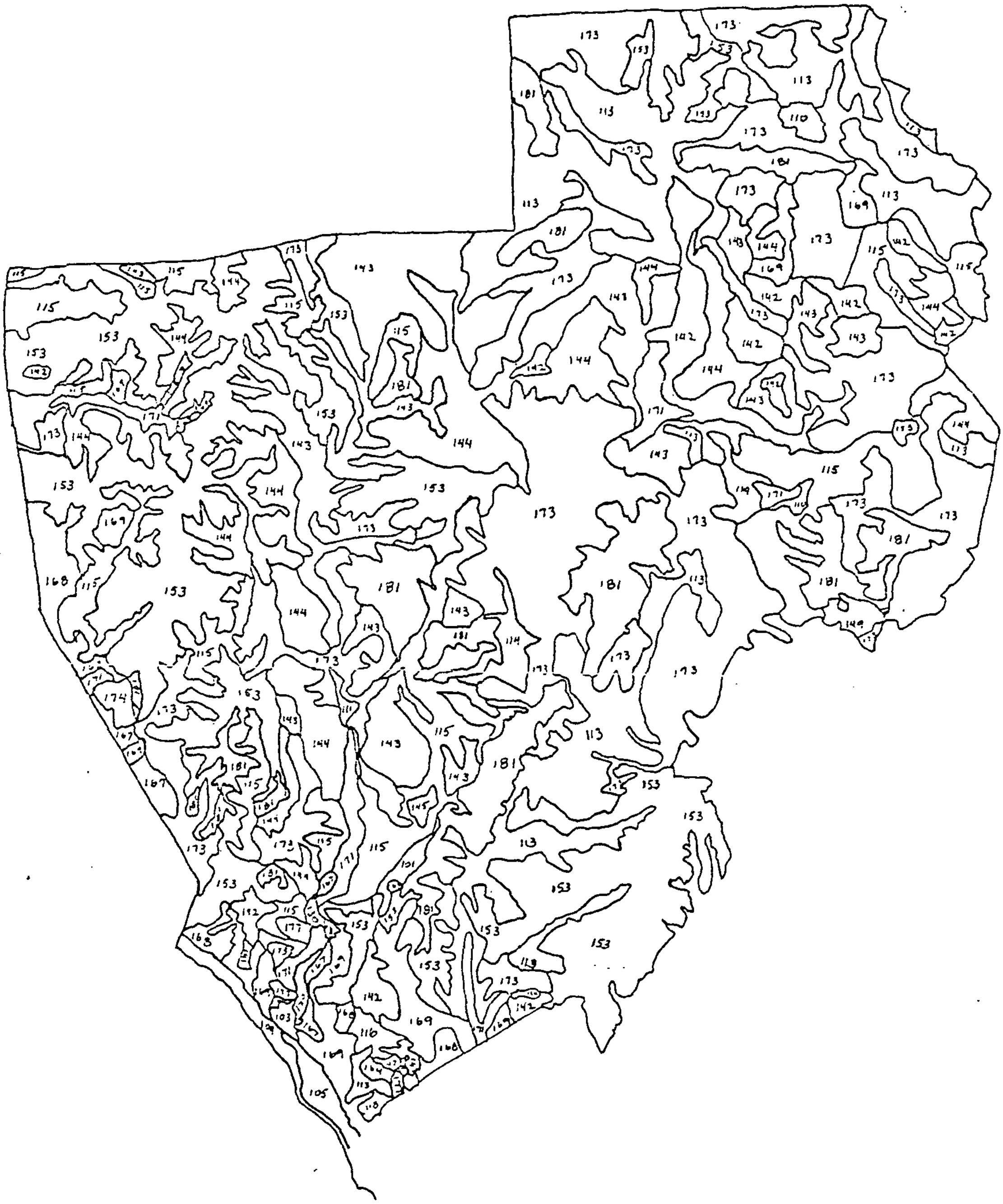

Figure 1. This soil map was mosaicked together from existing Soil Conservation Service maps for the Santa Cruz, California area. The map was digitized and input to the Big Basin State Park data bank.

2.3.2 The hypsographic component was registered to the UTM data base using a procedure similar to that described in 2.3.1. The regression coefficients input to COTRAN, however, were based on a set of four control points that referenced the corners of the 1°-by-1° San Francisco West quadrangle. The digitized coordinate pairs were measured from the map sheet.

2.3.3 The soil component was initially transformed from a map format to a digital format. Each soil type boundary was outlined on a Talos coordinate digitizing table and was transformed to a series of X-Y coordinate strings. Three control points on the map were also digitized, and the Talos X-Y coordinates of these points were compared to their respective UTM coordinates. The regression coefficients were calculated between Talos and UTM coordinate systems. The coefficients were input to the general data handling program, "MAPIT", which converted the Talos coordinate strings to UTM coordinate strings. The closed UTM coordinate strings were further transformed to a grid format of 60-by-60 meters in which each cell of the grid represented one of the 36 soil series present on the map.

2.3.4 The boundary component map was transformed to a series of X-Y coordinates using a procedure similar to that described in 2.3.3. Regression coefficients were calculated between the Talos and CDF coordinate systems through the intermediary UTM-CDF regression transformation developed in 2.3.1. In this way, the boundary component map could be overlaid on the CDF data set prior to its rotation. The resulting CDF coordinate strings were input to MAPIT to produce two mask bands. In the first, all cells within the Park were coded "1", and all cells outside were coded "0". In the second, all cells falling along the edge of the Park boundary were coded "0", and all other cells were coded "1". The digitized edge map is shown in Figure 2.

The two mask bands were overlaid on the CDF data set prior to its rotation to the UTM data base. The first mask band was overlaid on the classified CDF data. As a result, the total of 36 spectral classes present in the rectangular area were reduced to 20 classes present within the Park boundary. The second "edge" band was overlaid on the four bands of raw spectral data in order to provide a visual check on the accuracy of the overlay procedure and a display of the location of the Park within the larger geographic area. It is important to emphasize that the two

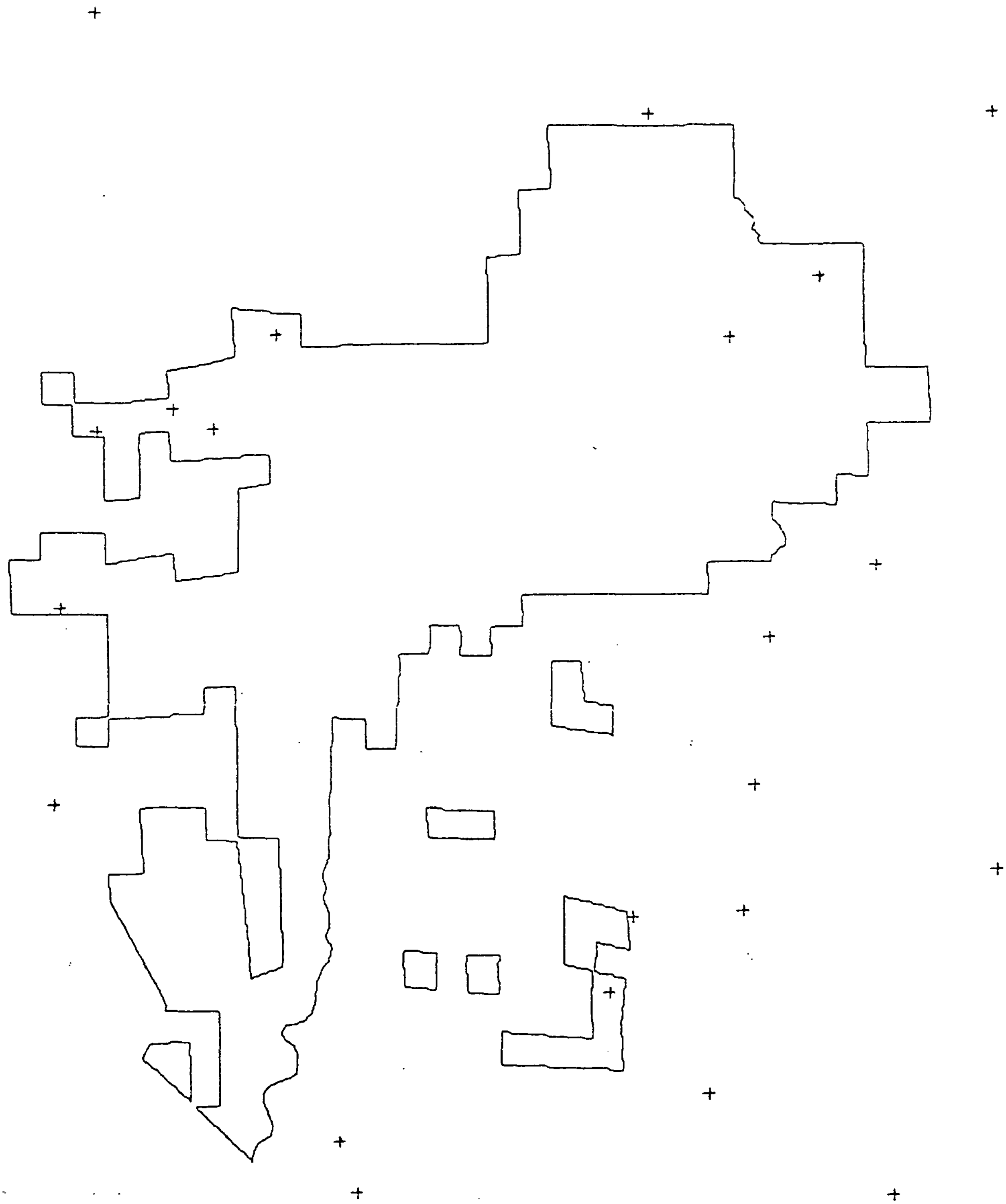

Figure 2. This line map, drawn by the CALCOMP plotter, represents the boundary component input to the Big Basin State Park digital data bank. The "+" symbols represent the 23 control points used to overlay the Landsat data to the data bank coordinates.

mask bands were overlaid on the CDF data prior to its rotation as described in 2.3.1. In this way, the accuracy of the boundary overlay was verified before any confounding errors could be introduced by the rotation process.

2.4 Generation of Data Bands

Once the four components had been registered to the UTM coordinate grid, they were input as separate bands to the digital data bank. Additional bands were created by either simple mathematical manipulation or by aggregating the classes in the original bands. A listing of the 20-band data bank that has resulted from these operations is given in Table 1.

2.4.1 The only modification performed on the CDF spectral component (Bands 3, 4, 5, and 6) was to generate a vegetation indicator band (20). This band was calculated by dividing the value of the reflectance infrared band (6) by the value of the visible red band (4) for each cell in the Park. After sufficient ground data have been collected, it may be possible to establish a correlation between this ratio and the fuel loads within the Park, since the ratio is a good indicator of general vegetation density and condition. The ratio retains most of the spectral information regarding vegetation development while tending to normalize the influence of such confounding factors as solar radiation and topography. Generally speaking, if the calculated ratio exceed 1.09, the cell represents actively metabolizing vegetation; if the calculated ratio is less than 1.09, the cell represents such conditions as snow, water, dried vegetation, or bare soil.

The 36-class CDF classified component (Band 2) was aggregated to produce a six-class generalized vegetation band (10) and a 20-class band (19) in which like vegetation classes were numbered in consecutive order and the grassland classes and the barren, water, and "other" classes were combined. The listing of these three bands is given in Table 2a, and a description of the band labels is given in Table 2b.

2.4.2 The digitized elevation values of the hypsographic component were manipulated with the general data handling program, MAPIT, to produce a 66-class contour band (9), a 49-class aspect band (8), and a 26-class slope band (7).

Table 1. Big Basin Digital Data Bank

Band Number	Name	Source	Description
1	SOIL$30	SCS Santa Cruz soil maps	soil sub-series
2	VEG$36	CDF statewide Landsat mosaic, classified	vegetation sub-classes
3	VMSS4(E)[1]	CDF statewide Landsat mosaic, raw	Landsat green-edge mask applied
4	VMSS5(E)[1]	CDF statewide Landsat mosaic, raw	Landsat red-edge mask applied
5	VMSS6(E)[1]	CDF statewide Landsat mosaic, raw	Landsat near reflectance infrared-edge mask applied
6	VMSS7(E)[1]	CDS statewide Landsat mosaic, raw	Landsat far reflectance infrared-edge mask applied
7	SLOPE$26	USGS digital terrain tape, MAPIT	flat + 5% slope interval
8	ASPCT$49	USGS digital terrain tape, MAPIT	flat + 7.5° aspect interval
9	CONT$66	USGS digital terrain tape, MAPIT	sea level + 40 foot contour interval
10	VEG$6	Band 2	major vegetation types
11	ASPECT$5	Band 8	flat + 90° aspect interval
12	ASPECT$9	Band 8	flat + 45° aspect interval
13	SLP$NFDR	Band 7	National Fire Danger Rating System slope classes
14	SLP$FMC	Band 7	fuel management slope classes
15	SOIL$22	Band 1	soil series
16	SLOPE$8	Band 7	flat + 20% slope interval
17	SLOPE$6	Band 7	flat + 25% slope interval
18	CONT$8	Band 9	flat + 400 ft. contour interval
19	VEG$20	Band 2	renumbered vegetation sub-classes
20	VI	Band 6 and Band 4	vegetation indication (Band 6/Band 4)

[1] VMSS refers to multispectral scanner data that are in the VICARS format

Table 2a. The vegetation component and aggregated bands of the Big Basin State Park digital data bank.

Class Number	BAND 2 VEG$36[1] Description
0	fill
1	conifer-1
2	brush-1
4	grassland-1
5	conifer-3
6	conifer/hardwood-1
7	brush-1
8	hardwood/woodland-1
9	hardwood/woodland-2
10	conifer/hardwood-2
11	hardwood/woodland-3
12	hardwood/woodland-4
13	hardwood/conifer-1
14	hardwood/woodland-5
15	hardwood-1
16	hardwood-2
17	hardwood-3
18	hardwood/woodland-6
19	grassland-2
20	shrub-1
21	grassland-3
22	grassland-4
23	grassland-5
24	grassland-6
25	grassland-7
26	barren-1
27	water-1
28	water-2
29	grassland-8
30	grassland-9
31	barren-2
32	barren-3
33	barren-4
34	other
35	other
36	other

Class Number	BAND 10 VEG$6[2] Description
0	fill
1	conifer(3)
2	brush(3)
4	hardwood(3)
5	hardwood/woodland(7)
6	grassland(6)

Class Number	BAND 19 VEG$20[2] Description
0	fill
1	conifer-1
2	conifer-2
3	conifer-3
4	hardwood-1
5	hardwood-2
6	hardwood-3
7	brush-1
8	brush-2
9	shrub-1
10	grassland(9)
11	conifer/hardwood-1
12	conifer/hardwood-2
13	hardwood/conifer-1
14	hardwood/woodland-1
15	hardwood/woodland-2
16	hardwood/woodland-3
17	hardwood/woodland-4
18	hardwood/woodland-5
19	hardwood/woodland-6
20	other(9)

[1] Input component from the CDF data set

[2] Aggregated band from the CDF data set input component

Table 2b. Class Descriptions for Table 2a.

CLASS DESCRIPTIONS

Bare Rock

Water

Agriculture (pattern recognition)

Urban (may be residential and/or commercial)

Alkali Flats

Barren (predominantly bare soil, less than 5% vegetative cover)

Grassland - Vegetation predominantly grass. Cover greater than 5%. May be annual or perennial grasslands. Less than 10% tree cover. May include herbaceous vegetation.

Desert Shrub - Vegetation consists of xeric shrubs, generally open with much bare soil and desert pavement exposed. However, dense stands may occur. Vegetation ranges from .5 to 3 meters tall. Less than 10% tree canopy closure. Generally found on flat or slightly sloping terrain.

Brush - Open to dense (greater than 5% ground cover) evergreen or deciduous shrubs, rarely more than 5 meters tall (usually 1-3 m.). May have herbaceous understory. Less than 10% tree canopy closure. This includes riparian vegetation along waterways.

Hardwood-Woodland - Scattered hardwoods (deciduous and evergreen), 10-25% canopy closure. May have grass or brush understory.

Conifer-Woodland - Scattered conifers, 10-25% canopy closure, often with an herbaceous or brush understory.

Hardwood - Greater than 25% canopy closure of hardwood species. Less than 20% conifer in the stand. May have an herbaceous or brush understory.

Hardwood-Conifer - Greater than 25% canopy closure, with hardwoods comprising greater than 50% but less than 80% of the stand. Conifers comprise 20-50% of the stand. There may be an herbaceous or shrub understory.

Conifer-Hardwood - Greater than 25% canopy closure, with conifer species comprising greater than 50%, but less than 80% of the stand. Hardwood species comprise 20-40% of the stand. There may be an herbaceous or brush understory.

Conifer - Greater than 25% crown closure of conifer species. Less than 20% hardwood in the stand. There may be an herbaceous or brush understory.

The contour band was produced by simply combining the original digital classes into a sea-level class and 40-foot contour interval classes which resulted in a total of 66 classes. This band was subsequently aggregated to produce a 400-foot contour interval band (18). A listing of contour bands 9 and 18 is given in Table 3.

Through the application of MAPIT, the slope and aspect bands were produced as follows. For each cell a normal vector was calculated which represented the "best fit" plane as defined by the DTT elevation values from the four adjacent cells. The slope of the center cell was defined by the minimum angle between the normal vector and the horizontal plane; the corresponding aspect was defined by the rotation angle of the horizontal projection of the normal vector.

The primary aspect band (8) was produced by combining the calculated aspect classes into a flat class and $7\frac{1}{2}°$ interval classes (starting at north and progressing eastward) which resulted in a total of 49 classes. This band was subsequently aggregated to produce a 90°-aspect band (11) and a 45°-aspect band (12). A listing of aspect bands 8, 11, and 12 is given in Table 4.

The primary slope band (7) was produced by combining the calculated slope classes into a flat class and 5% interval classes which resulted in a total of 26 classes. This band was subsequently aggregated to produce a 20% slope interval band (16), a 25% slope interval band (17), a National Fire Danger Rating System (NFDRS) slope class band (13), and fuel management slope class band (14). A listing for slope bands 7, 16, 17, 13, and 14 is given in Table 5. The fuel management slope classes are those which limit or preclude the use of tractors and tractor-towed implements for fuel modification because of steepness of slope and/or soil stability. The NFDRS slope classes are those which are input to fuel spread models developed by Deeming, et al., (1976).

2.4.3 The 30-class soil subseries component (Band 1) was aggregated to produce a 20-class soil series band (15) by combining those soil subseries which differed only by the percent slope modifier. A listing of the soils bands, 1 and 15, is given in Table 6.

2.4.4 The two-band boundary component was input as separate bands to the data bank. As described in Section 2.3.4, the edge band was overlaid on

Table 3. The contour bands from the hypsographic component of the Big Basin State Park digital data bank.

BAND 9 CONT$66

Class Number	Contour Interval	Class Number	Countour Interval	Class Number	Contour Interval
0	sea-level		1000'		2000'
1		26		51	
	40'		1040'		2040'
2		27		52	
	80'		1080'		2080'
3		28		53	
	120'		1120'		2120'
4		29		54	
	160'		1160'		2160'
5		30		55	
	200'		1200'		2200'
6		31		56	
	240'		1240'		2240'
7		32		57	
	280'		1280'		2280'
8		33		58	
	320'		1320'		2320'
9		34		59	
	360'		1360'		2360'
10		35		60	
	400'		1400'		2400'
11		36		61	
	440'		1440'		2440'
12		37		62	
	480'		1480		2480'
13		38		63	
	520'		1520'		2520'
14		39		64	
	560'		1560'		2560'
15		40		65	
	600'		1600'		2600'
16		41			
	640'		1640'		
17		42			
	680'		1680'		
18		43			
	720'		1720'		
19		44			
	760'		1760'		
20		45			
	800'		1800'		
21		46			
	840'		1840'		
22		47			
	880'		1880'		
23		48			
	920'		1920'		
24		49			
	960'		1960'		
25		50			
	1000'		2000'		

BAND 18 CONT$8

Class Number	Contour Interval
0	sea-level
1	
	400'
2	
	800'
3	
	1200'
4	
	1600'
5	
	2000'
6	
	2400'
7	
	2400+'

Table 4. The aspect portion of the hypsographic component of the Big Basin State Park digital data bank.

BAND 8 ASPECT$49

Class Number	Aspect Interval	Class Number	Aspect Interval
0	flat		180.0°
1	7.5°	25	187.5°
2	15.0°	26	195.0°
3	22.5°	27	202.5°
4	30.0°	28	210.0°
5	37.5°	29	217.5°
6	45.0°	30	225.0°
7	52.5°	31	232.5°
8	60.0°	32	240.0°
9	67.5°	33	247.5°
10	75.0°	34	255.0°
11	82.5°	35	262.5°
12	90.0°	36	270.0°
13	97.5°	37	277.5°
14	105.0°	38	285.0°
15	112.5°	39	292.5°
16	120.0°	40	300.0°
17	127.5°	41	307.5°
18	135.0°	42	315.0°
19	142.5°	43	322.5°
20	150.0°	44	330.0°
21	157.5°	45	337.5°
22	165.0°	46	245.0°
23	172.5°	47	352.5°
24	180.0°	48	360.0°

BAND 11 ASPECT$5

Class Number	Aspect Interval
0	flat
1(N)	315.0°
2(E)	45.0°
3(S)	135.0°
4(W)	225.0°
	315.0°

BAND 12 ASPECT$9

Class Number	Aspect Interval
0	flat
	337.5°
1(N)	22.5°
2(NE)	67.5°
3(E)	112.5°
4(SE)	157.5°
5(S)	202.5°
6(SW)	247.5°
7(W)	292.5°
8(NW)	337.5°

Table 5. The slope bands of the hypsographic component of the Big Basin State Park digital data bank

BAND 7 — SLOPE$26

Class Number	Slope Interval
0	flat
1	
2	5%
3	10%
4	15%
5	20%
6	25%
7	30%
8	35%
9	40%
10	45%
11	50%
12	55%
13	60%
14	65%
15	70%
16	75%
17	80%
18	85%
19	90%
20	95%
21	100%
22	105%
23	110%
24	115%
25	120%
	125%

BAND 13 — SLP$NFDR[1]

Class Number	Slope Interval
0	flat
1	
2	25%
3	40%
4	55%
5	75%
	75+%

BAND 14 — SLP$FMC[2]

Class Number	Slope Interval
0	flat
1	
2	30%
3	50%
4	65%
	65+%

BAND 16 — SLOPE$8

Class Number	Slope Interval
0	flat
1	
2	20%
3	40%
4	60%
5	80%
6	100%
7	120%
	120+%

BAND 17 — SLOPE$6

Class Number	Slope Interval
0	flat
1	
2	25%
3	50%
4	75%
5	100%
	125%

[1]National Fire Danger Rating System slope classes.

[2]Fuel management slope classes.

Table 6. The soil component of the Big Basin State Park digital data bank

BAND 1 SOIL$30

Class Number	Description
0	fill
1	101-Aptos loam
2	103-Aquents flooded
3	105-Baywood loamy sand
4	109-Beaches
5	110-Ben Lomand sandy loam 5-15%
6	111-Ben Lomand sandy loam 15-50%
7	113-Ben Lomand-Catelli Sur
8	114-Ben Lomand-Felton complex 15-30%
9	115-Ben Lomand-Felton complex 30-75%
10	116-Bonnydoon loam
11	130-Elder sandy loam
12	138-Felton sandy loam
13	141-Heckler gravelly sandy loam
14	142-Lompico-Felton complex 5-30%
15	143-Lompico-Felton complex 30-50%
16	144-Lompico-Felton complex 50-75%
17	145-Lompico Variant loam
18	147-Los Osos loam
19	149-Madonna loam
20	153-Maymen-rock outcrop complex
21	167-Santa Lucia shaly clay loam 5-30%
22	168-Santa Lucia shaly clay loam 30-50%
23	169-Santa Lucia shaly clay loam 50-75%
24	170-Soquel loam 0-2%
25	171-Soquel loam 2-9%
26	172-Soquel loam 9-15%
27	173-Sur Catelli
28	174-Tierra-Watsonville complex
29	177-Watsonville loam
30	181-Xerorthents-Roch outcrop

BAND 15 SOILS$23

Class Number	Description
0	fill
1	101
2	103
3	105
4	109
5	110,111
6	113*
7	114,115*
8	116
9	130
10	138
11	141
12	142,143,144*
13	145
14	147
15	149
16	153*
17	167,168,169*
18	170,171,172*
19	173*
20	174
21	177
22	181*

*Present within the boundary of Big Basin State Park.

the four spectral bands (3, 4, 5, and 6), and a mask band was applied to the classified Landsat band (2). There was no need to permanently overlay either the edge or mask band to the other bands because they could be recalled from band 2, or from bands 3, 4, 5, or 6 in the bank, as needed. For example, by applying the mask to the soils band (15), the 20-class soils map was reduced to only eight soil series that were present within the Park boundary; by applying the mask to the elevation band (18), the sea level class was eliminated.

3.0 Preliminary Analysis of the Big Basin Data Bank

3.1 The Chi Square Test

A number of contingency tables were constructed from scattergrams which plotted the joint occurrence of given classes between pairs of the bands listed in Table 1. An example of the contingency table for bands 11 and 10 is shown in Table 7. Of the total possible tables that could have been constructed from the data set, six were deemed more appropriate to the project objective: bands 15 and 19, bands 15 and 10, bands 12 and 10, bands 11 and 10, bands 18 and 2, and bands 13 and 19. Chi-square analyses were performed on these six tables to test the hypothesis of independence. The chi-square analysis performed on the contingency table shown in Table 7 is given in Table 8. The results of the six analyses are summarized in Table 9.

The hypothesis of independence states that the distribution of the classes in one band is random, or independent of the distribution of the classes in another band. If there is no independence, as evidenced by a large calculated chi-square value, an interaction is said to be present. This implies that the distribution of all or some of the classes in one band is dependent upon all or some of the classes in the other band.

For each cell of the contingency table, the chi-square statistic is calculated as follows:

$$\text{Chi-square} = \frac{(\text{Ob} - \text{Ex})^2}{\text{Ex}}$$

$$\equiv \frac{\overset{\text{row}}{\Sigma \text{Ob}}}{\underset{\Sigma \text{Ob}}{\text{table}}} \times \frac{\overset{\text{column}}{\Sigma \text{Ob}}}{\underset{\Sigma \text{Ob}}{\text{table}}} \times \overset{\text{table}}{\Sigma \text{Ob}}$$

where: Ob = observed value of joint occurrence for that cell, and
Ex = expected random occurrence for that cell

Table 7. Contingency table for the joint occurrence of Aspect (Band 11) and Vegetation (Band 10) in Big Basin State Park, California

ASPECT	VEGETATION						
	Conifer	Brush	Conifer/ Hardwood	Hardwood	Hardwood/ Woodland	Grassland	Row
Flat	136	28	184	73	156	31	608
North	816	76	789	258	338	30	2307
East	334	227	787	1256	1158	111	3873
South	402	319	1044	774	1634	250	4423
West	1542	356	1341	370	943	123	4675
Column	3230	1006	4145	2731	4229	545	15886

Table 8. The chi-square test as run on the contingency table for Vegetation (Band 10) and Aspect (Band 11).

	CONIFER	BRUSH	CONIFER/ HARDWOOD	HARDWOOD	HARDWOOD/ WOODLAND	GRASSLAND	ROW SUM
FLAT	136	28	184	73	156	31	608
EXPECTED	123.621	38.502	158.640	104.523	161.855	20.859	
CHI SQ	1.240	2.865	4.054	9.507	.212	4.931	22.808
NORTH	816	76	789	258	338	30	2307
EXPECTED	469.068	146.094	601.946	396.602	614.145	79.146	
CHI SQ	256.598	33.630	58.127	48.438	124.166	30.517	551.475
EAST	334	227	787	1256	1158	111	3873
EXPECTED	787.472	245.262	1010.549	665.816	1031.028	132.871	
CHI SQ	261.136	1.360	49.453	523.142	15.637	3.600	854.326
SOUTH	402	319	1044	774	1634	250	4423
EXPECTED	899.301	280.092	1154.056	760.368	1177.443	151.740	
CHI SQ	275.000	5.405	10.495	.244	177.031	63.629	531.804
WEST	1542	356	1341	370	943	123	4675
EXPECTED	950.538	296.050	1219.808	803.690	1244.528	160.385	
CHI SQ	368.031	12.140	12.041	234.029	73.055	8.714	708.010
COLUMN SUMS	3230	1006	4145	2731	4229	545	
COL CHI SUMS	1162.004	55.399	134.169	815.360	390.100	111.392	

TOTAL SUM =15886.   DEGREES OF FREEDOM = 20   CHI SQUARED = .266842E 04

SAMPLE CALCULATIONS: EAST-BRUSH

Row total - East   Column total - Brush

$$\text{EXPECTED} = \frac{3873}{15886} \times \frac{1006}{15886} \times 15886 = \underline{\underline{245.262}}$$

Total observed

Observed

$$\text{CHI-SQUARE} = \frac{(227 - 245.262)^2}{245.262} = \underline{\underline{1.360}}$$

Expected

Table 9. Summary of preliminary chi-square analyses of the Big Basin State Park data bank.

Run No.	Soil Component Vs. Vegetation Component	No. Of Obser-vations	Degrees Of Freedom	χ^2
1	Band 15 (8 classes) vs. Band 19 (20 classes)	15632	126	5351
2	Band 15 (8 classes) vs. Band 10 (6 classes)	15632	35	2866
	Aspect Band Vs. Vegetation Component			
3	Band 12 (9 classes) vs. Band 10 (6 classes)	15928	40	2910
4	Band 11 (5 classes) vs. Band 10 (6 classes)	15928	20	2698
	Contour Band Vs. Vegetation Component			
5	Band 18 (6 classes) vs. Band 2 (19 classes)	15959	90	1996
	NFDRS Slope Band Vs. Vegetation Component			
6	Band 13 (5 classes) vs. Band 19 (19 classes)	15948	72	907

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	NFDRS Slope Band Vs. Vegetation Component			
6	Band 13 (5 classes) vs. Band 19 (19 classes)	15948	72	907

The chi-square values are summed for all cells to give the chi-square value for the table with (row-1)(column-1) degrees of freedom.

In order for the chi-square test to be valid, the expected frequencies in each cell should not be too small. Obviously, no cell should have an expected frequency of less than 1; and Cochran (1954) further recommends that no more than 20 percent of the cells should have expected frequencies of less than 5. In order to meet these constraints, some classes from a given band may be combined with another class, or eliminated from the table altogether.

A large chi-square value indicates dependence between the bands. Critical chi-square values are available in most statistical text books. If these tables are not available, the following rule can be used to determine the presence or absence of an interaction between bands: If the calculated chi-square value for the contingency table is near the number of degrees of freedom, the bands are distributed independently of each other. However, if the calculated chi-square value exceeds three times the number of degrees of freedom, the distribution of the classes of one band with respect to those of another band cannot be attributed to random variation.

For testing the hypothesis of independence between bands of the Big Basin State Park data bank, the "three times degrees of freedom" rule may be a more appropriate measure of independence than the critical value extracted from a statistical table. The table values assume that the measurement of joint occurrence has been made withour error. Although we attempted to exactly overlay the different components of the data bank to a common base, some mapping error was inevitably introduced during the resampling procedures (see Section 2.3). While the extent of this error was different for each input component, it never exceeded one half of the 60-meter cell. However, because the overlay error could cause misleadingly high chi-square values for individual cells, the conservative "three times" rule was used.

3.1.1 The Soil Component versus the Vegetation Component

Two sets of analysis were performed: run 1 -- Soil Series (8 classes) versus Vegetation (19 classes), and run 2 -- Soil Series (8 classes) versus Vegetation (6 classes). For both runs the original soil subseries classes

(Band 1) were either lumped into the eight major soil series classes present within the Park or eliminated from the analyses if they did not occupy sufficient area to meet the chi-square constraints given in Section 3.1. For run 1, six grassland subclasses were lumbed into one class in order to prevent the occurrence of expected values of less than 1.

Both runs 1 and 2 had large calculated chi-square values so that we must conclude that the distribution of soil series classes and vegetation type classes is not independent within the Park. Also, we can conclude that the distribution of some vegetation types is more influenced by some soil types than by others as is evidenced by the chi-square column totals. For example, by examining chi-square column totals in run 1, it was clear that the distribution of conifer subclasses 1 and 3 was much more dependent on soil type than was that of conifer subclass 2 (chi-square 101.894 and 177.472>>35.406). Further, by examining the individual cell chi-square values, it was clear that the presence of conifer-1 was more dependent on soil series 167-9 than was that of conifer-3 (chi-square 43.798>>2.452), and conversely, the presence of conifer-3 was more dependent on soil series 142-4 than was that of conifer-1 (chi-square 79.409>>12.432).

Based on the results of both run 1 and run 2, we would recommend that either the soil component or the vegetation component be used in constructing the final sampling frame. Since there is a high measure of dependence between these two components, the use of both would be redundant. For the purposes of constructing the frame, the vegetation component with its inherent finer resolution (nominal pixel size ≃ 1.6 acres) would be preferable to the soils component (nominal minimum mapping area = 10-20 acres).

3.1.2 The Aspect Band versus the Vegetation Component

Two sets of analyses were preformed: run 3 -- Aspect (9 classes) versus Vegetation (6 classes) and run 4 -- Aspect (5 classes) versus Vegetation (6 classes). Both runs 3 and 4 had large calculated chi-square values, so we must conclude that the distribution of vegetation classes was dependent on aspect within the Park. Again, by examining the chi-square column totals in run 3, we further concluded that the distribution of the pure conifer and hardwood vegetation classes was more influenced by aspect than was that of other types (chi-square 1259.506 and 935.419). Also, by examining the chi-square row totals we concluded that the distribution of the vegetation types was most heavily influenced on the southeast and northwest aspects (chi-square 643.485 and 623.522).

3.1.3 The Contour Band versus the Vegetation Component

One analysis was performed: run 5 -- Contour (6 classes) versus Vegetation (19 classes). The calculated chi-square was significant, indicating that the distribution of vegetation within the Park was correlated with elevation zones.

3.1.4 The Slope Band versus the Vegetation Component

One analysis was performed: run 6 -- National Fire Danger Rating Slope (5 classes) versus Vegetation (19 classes). The calculated chi-square was significant, indicating that the distribution of the vegetation within the Park was correlated with slope.

3.1.5 Conclusions drawn from the Chi-square Analyses

None of the results described in these sections are startling. Plant ecologists have known for many years that there is a close interaction between the distribution of soils, vegetation, aspect, elevation and slope. However, based on these chi-square analyses, we can quantify the degree of this interaction. Since all analyses indicated high correlations, we can conclude that there is a great deal of redundancy between these components. Therefore, we would recommend that the vegetation band be used as the sampling frame for the Park. Since this band is correlated highly with the other bands, by allocating samples proportionally to the vegetation classes we should also account for the class ranges in the slope, aspect, elevetion, and soil gradients.

3.2 Analysis of Multi-Dimensional Histograms

At the request of the Department of Parks and Recreation, personnel from the RSRP developed the needed software so that multidimensional histograms could be produced for selected bands from the Big Basin data bank. It was hoped that the resulting histograms could be used to allocate ground samples more efficiently than could be done from the results of the pair-wise chi-square analyses.

Two multidimensional histograms were constructed for three and four bands, respectively: Vegetation (19 classes) x Aspect (5 classes) x Elevation (7 classes); and Vegetation (19 classes) x Aspect (5 classes) x Elevation (7 classes) x Soils (8 classes). An example of the output for the three-band histogram which has been sorted for the three conifer classes is shown in Table 10 and a summary of the three and four-band histogram is given in Table 11a and 11b.

Based on the initial analysis of the two multidimensional histograms, we concluded that neither would be useful for defining the ground sample framework, because either histogram would require too large a ground sample if multiple samples were to be allocated to each vector. Although the histograms indicate correlation between the bands (the number of observed vectors was less than the number of possible vectors), the correlation should have been higher. Many of the unique vectors had only one to five ovservations which were probably noise that was caused by the inherent errors of overlaying data from different components. Until the overlay process can be done with less error, which may not be possible with the quality of many sources of input data to data banks, the analysis of multiband histograms may not be appropriate.

4.0 Results and Future Work

Based on the chi-square analyses, we decided to proportionally allocate the ground sample based on the number of spectral vegetation classes in Band 19. A random number generator was used to selex pixels within each vegetation class to represent ground samples. A listing of the pixels selected for the conifer-1 class, along with the associated hypsographic, soil, and ground coordinate data, is given in Table 12. A thematic map, representing the conifer-1 class and the selected ground data points within that class, is given in Figure 3.

Throughout the summer and fall of 1981, personnel from the Santa Cruz campus will be performing field work in the Big Basin State Park to verify the accuracy of the data bank. In order to carry out this effort, the UTM east and north coordinates were plotted to orthophoto map sheets, and these coordinate pairs were transferred in turn to large-scale aerial photography. The annotated aerial photos will be used by personnel in the field to navigate to each spot at which field observations must be made.

Table 10. An example of the three-band histogram that was sorted on the conifer classes of Band 19 of the Big Basin digital data bank.

Count	Vegetation #	Vegetation Label	Aspect #	Aspect Label	Elevation #	Elevation Label
7	1	CON-1	0	FLAT	1	0-400
2	1	CON-1	0	FLAT	2	400-800
1	1	CON-1	0	FLAT	3	800-1200
7	1	CON-1	1	N	1	0-400
26	1	CON-1	1	N	2	400-800
22	1	CON-1	1	N	3	800-1200
17	1	CON-1	1	N	4	12-1600
[illegible]	1	CON-1	2	E	1	0-400
[illegible]	1	CON-1	2	E	2	400-800
5	1	CON-1	2	E	3	800-1200
[illegible]	1	CON-1	3	S	1	0-400
[illegible]	1	CON-1	3	S	2	400-800
3	1	CON-1	3	S	3	800-1200
2	1	CON-1	3	S	4	12-1600
26	1	CON-1	4	W	1	0-400
65	1	CON-1	4	W	2	400-800
53	1	CON-1	4	W	3	800-1200
3	1	CON-1	4	W	4	12-1600
1	1	CON-1	4	W	5	16-2000
9	2	CON-2	0	FLAT	1	0-400
5	2	CON-2	0	FLAT	2	400-800
[illegible]	2	CON-2	0	FLAT	3	800-1200
[illegible]	2	CON-2	0	FLAT	4	12-1600
[illegible]	2	CON-2	1	N	1	0-400
41	2	CON-2	1	N	2	400-800
112	2	CON-2	1	N	3	800-1200
53	2	CON-2	1	N	4	12-1600
3	2	CON-2	1	N	5	16-2000
8	2	CON-2	2	E	1	0-400
76	2	CON-2	2	E	2	400-800
43	2	CON-2	2	E	3	800-1200
7	2	CON-2	2	E	4	12-1600
2	2	CON-2	2	E	5	16-2000
[illegible]	2	CON-2	3	S	1	0-400
41	2	CON-2	3	S	2	400-800
57	2	CON-2	3	S	3	800-1200
[illegible]	2	CON-2	3	S	4	12-1600
1	2	CON-2	3	S	5	16-2000
[illegible]	2	CON-2	4	W	1	0-400
135	2	CON-2	4	W	2	400-800
[illegible]	2	CON-2	4	W	3	800-1200
121	2	CON-2	4	W	4	12-1600
[illegible]	2	CON-2	4	W	5	16-2000
6	3	CON-3	0	FLAT	1	0-400
[illegible]	3	CON-3	0	FLAT	2	400-800
[illegible]	3	CON-3	0	FLAT	3	800-1200
[illegible]	3	CON-3	0	FLAT	4	12-1600
14	3	CON-3	1	N	1	0-400
67	3	CON-3	1	N	2	400-800
213	3	CON-3	1	N	3	800-1200
197	3	CON-3	1	N	4	12-1600
21	3	CON-3	1	N	5	16-2000
37	3	CON-3	2	E	1	0-400
40	3	CON-3	2	E	2	400-800
51	3	CON-3	2	E	3	800-1200
34	3	CON-3	2	E	4	12-1600
2	3	CON-3	2	E	5	16-2000
18	3	CON-3	3	S	1	0-400
56	3	CON-3	3	S	2	400-800
79	3	CON-3	3	S	3	800-1200
76	3	CON-3	3	S	4	12-1600
6	3	CON-3	3	S	5	16-2000
35	3	CON-3	4	W	1	0-400
158	3	CON-3	4	W	2	400-800
334	3	CON-3	4	W	3	800-1200
238	3	CON-3	4	W	4	12-1600
38	3	CON-3	4	W	5	16-2000
1	3	CON-3	4	W	6	20-2400

Table 11. Summary of three-band (a) and four-band (b) multiband histogram for Big Basin State Park, California.

(a) Three-band histogram: Vegetation (19 classes) x Aspect (5 classes) x Elevation (7 classes)

Number of Pixels: 15,958

Total number of unique three-band vectors: 437

Total number of possible three-band vectors: 19 x 5 x 7 = 665

Range of vector counts: 1 to 330

(b) Four-band histogram: Vegetation (19 classes) x Aspect (5 classes) x Elevation (7 classes) x Soil (8 classes)

Number of Pixels: 15,958

Total number of unique four-band vectors: 1,674

Total number of possible four-band vectors: 19 x 5 x 7 x 8 = 5,320

Range of vector counts: 1 to 283

Table 12. A listing of the randomly selected Conifer-1 pixels which will be verified in the field in the summer and fall of 1981. The distribution of these pixels with respect to the Conifer-1 class within Big Basin State Park is shown in Figure 3.

Point	Line	UTM East	UTM North	Band 11		Band 15		Band 18		Band 19	
X	Y	X	Y	1	(ASPECT$5)	2	(SOIL$23)	3	(CONT$8)	4	(VEG$20
218	63	570080.0	4117380.0	4	W	19	173	4	12-1600	1	CON-1
219	64	570140.0	4117320.0	4	W	19	173	5	16-2000	1	CON-1
212	86	569720.0	4116000.0	4	W	19	173	4	12-1600	1	CON-1
145	101	565700.0	4115100.0	4	W	12	142-144	2	400-800	1	CON-1
162	116	566720.0	4114200.0	2	E	12	142-144	2	400-800	1	CON-1
142	120	565520.0	4113960.0	2	E	7	114,115	2	400-800	1	CON-1
166	122	566960.0	4113840.0	1	N	19	173	3	800-1200	1	CON-1
167	123	567020.0	4113780.0	1	N	19	173	3	800-1200	1	CON-1
173	125	567380.0	4113660.0	4	W	19	173	3	800-1200	1	CON-1
156	128	566360.0	4113480.0	1	N	12	142-144	3	800-1200	1	CON-1
140	129	565400.0	4113420.0	2	E	12	142-144	1	0-400	1	CON-1
157	130	566420.0	4113360.0	1	N	12	142-144	4	12-1600	1	CON-1
137	134	565220.0	4113120.0	1	N	12	142-144	1	0-400	1	CON-1
144	134	565640.0	4113120.0	4	W	16	153	2	400-800	1	CON-1
2[illegible]8	135	569480.0	4113060.0	1	N	12	142-144	4	12-1600	1	CON-1
135	137	565100.0	4112940.0	1	N	12	142-144	2	400-800	1	CON-1
135	138	565100.0	4112880.0	4	W	12	142-144	2	400-800	1	CON-1
193	139	568560.0	4112820.0	1	N	19	173	3	800-1200	1	CON-1
91	172	562460.0	4110840.0	4	W	16	153	2	400-800	1	CON-1
109	188	563540.0	4109880.0	4	W	16	153	3	800-1200	1	CON-1
110	190	563600.0	4109760.0	4	W	16	153	3	800-1200	1	CON-1
1[illegible]0	198	563000.0	4109280.0	1	N	19	173	2	400-800	1	CON-1
116	209	563960.0	4108620.0	2	E	22	181	1	0-400	1	CON-1
116	215	563960.0	4108260.0	1	N	19	173	2	400-800	1	CON-1
104	238	563240.0	4106880.0	3	S	17	167-169	1	0-400	1	CON-1
106	239	563360.0	4106820.0	4	W	17	167-169	1	0-400	1	CON-1
132	240	564920.0	4106760.0	0	FLAT	17	167-169	1	0-400	1	CON-1

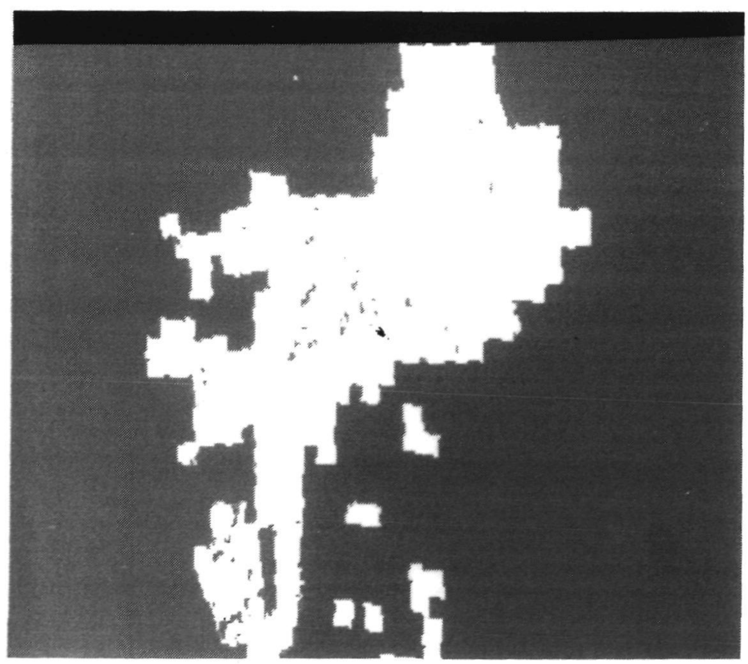

Figure 3. Distribution of the Conifer-1 class (yellow) within the Big Basin State Park (white). The blue pixels represent those of the conifer-1 class which were randomly selected for ground verification.

5.0 Literature Cited

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CENTRAL CALIFORNIA STUDIES

Co-investigator: John E. Estes

Scene Analysis for Wildland Fire-Fuels Characteristics
Using Landsat and Collateral Data

by

Michael J. Cosentino, Curtis E. Woodcock and Janet Franklin

Determining the Feasibility of Using Remote Sensing
Techniques to Detect Salinity Related
Cotton Canopy Reflectance Differences

by

Elaine Ezra

May, 1981

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SCENE ANALYSIS FOR WILDLAND FIRE-FUEL CHARACTERISTICS
USING LANDSAT AND COLLATERAL DATA

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3.1.1 Introduction

During the dry summer and fall seasons, wildfires are a threat to homes, lives, property, and natural resources in California. The perennial wildfire problem in Southern California results from the combination of densely populated areas scattered among broad expanses of highly flammable chaparral brushlands in rugged terrain, and hot, dry Santa Ana winds which often blow at speeds of from 100 to 160 km/hr. These conditions create an extremely explosive wildfire potential.

In California, the annual cost of extinguishing wildfires regularly exceeds $50 million. Damages directly attributable to wildfires can be devastating and often reach $100 million per year. However, the damage resulting from the fires does not end with the fire itself. Damages caused by erosion and flooding after a fire can be more severe and long lasting than those caused during the fire. The "fire and flood cycle" is initiated when a wildfire destroys the vegetative cover that protects the soil. Heavy winter rains cut deep into hillsides and ridges removing tons of topsoil. Unimpeded by vegetative cover, the runoff accumulates as it moves through the watershed. Not only can it destroy communities and take lives, but this mass of sediment-laden water and debris can fill reservoirs with silt, destroy streams and wildlife habitat, ruin grazing land, and cause mud-slides that strike homes, roads, and other structures.

Following a disastrous fire season in 1970, when wildfire destroyed 1,000 homes, killed 14 people, and burned over 200,000 hectares (500,000 acres) at a cost of $233 million for fire damage and suppression alone, Congress charged the U.S. Forest Service with development of a system for coordinating wildfire attack by federal, state, county, and municipal fire-fighting agencies in Southern California. The Congressional order resulted in the establishment of a program in 1972 called FIRESCOPE (Firefighting Resources of Southern California Organized for Potential Emergencies). The program serves 7 Southern California counties covering approximately 6.5 million hectares (16 million acres). The Operations Coordination Center in Riverside is staffed by Forest Service, California Department of Forestry, and California Office of Emergency Services personnel. During actual fire situations, these professionals, along with county and municipal fire chiefs, determine priorities for deployment of fire-fighting resources.

A computer program called FIREMOD, which will be used to predict fire spread rate and intensity, is currently being developed by FIRESCOPE. This computer simulation model requires data on vegetative fuel characteristics, terrain slope, wind speed and direction, and humidity. The simulation model predicts the location of fire perimeters in 6 to 12 hour burning periods, which can be used to assist in the allocation of firefighting resources. To provide the data to drive this model, automated weather towers have been installed along the Santa Ana wind channels to monitor changes in winds, air temperature and humidity. The stations transmit data via satellite to FIRESCOPE in Riverside to help predict the effect of imminent wind and weather changes on fire behavior. Digital terrain models are also being developed for the FIRESCOPE area to provide data for the FIREMOD computer model. Terrain slope angle exerts a significant influence on fire spread rate, and this effect has been quantified by Rothermel (1972) and Albini (1976). Therefore, two of the three data sets which drive the FIREMOD computer model are in place (weather and terrain). The third data set, which is site-specific information describing vegetative fuel characteristics, has yet to be developed. The purpose of this paper is to present the findings of a research project (NSG-7220) funded by NASA, Office of University Affairs and the U.S. Forest Service-FIRESCOPE Program, undertaken to evaluate the potential of using remotely sensed and collateral data in a geographic information system framework to provide maps of chaparral vegetation characteristics for input as a fuels database in the FIREMOD computer model.

3.1.2 Background

A fuels database, designed for use in fire spread simulation models, should describe the vegetation in terms of its effect on fire behavior. Rothermel (1972) and Albini (1976), among others, have developed methods for estimating fire behavior in terms of fire intensity and rate of spread. Fuel parameters wich are either directly input to the fire spread/intensity models, or considered in their construction, are those that describe properties of the chaparral which influence fire behavior. The physical characteristics of chaparral which affect fire behavior include spatial continuity, branching habit, size class distribution of the biomass, total and standing biomass, and the ratio of living to dead plant material (Philpot, 1977). Chaparral typically grows in dense, spatially continuous stands. Breaks in stand continuity will generally affect the momentum of fire propagation. The branching pattern of chaparral brush species is such that multiple stems originate from a root crown. This growth form results in a higher surface-area-to-volume ratio than single, large stemmed plants, which significantly impacts the heat release (intensity) and duration of burning. Another characteristic of chaparral vegetation which contributes to its flammability is the substantial increase in the amount of standing dead woody material as the plant ages. This parameter affects fire behavior because live fuel requires heat to drive off moisture before combustion can occur, and thus acts as a heat sink. Dead fuel, on the other hand, is readily ignited and available as a heat source (Rothermel and Philpot, 1973).

3.1.3 Study Area

The study area used in this research is a 7.5 minute quadrangle in the inland foothills and mountains northeast of Los Angeles in the Angeles National Forest. The area is characterized by a Mediterranean climate with warm-to-hot summers and mild winters, and a continuous marine influence. Winters are moderately moist (400 mm precipitation), summers are hot and dry, and include long periods of hot sun. There is a wide diversity of drought-resistant cover types in the study area, which represents most of the diversity in the Southern California fire prone areas. The vegetative cover consists of mixes of several types of chaparral, grassland, oaks, scattered conifer stands, and riparian vegetation. The majority of soils occur on steep slopes and are shallow and coarse-textured, with rocks and gravel throughout the matrix.

3.1.4 Approach

The approach adopted in this initial study is to use remotely sensed and collateral data to provide several types of spatial information about vegetation characteristics. The underlying assumption is that these vegetative characteristics are related to the parameters identified as important because such parameters as size class distribution of the biomass, live/dead ratio, and branching habit could not be directly ascertained from available remotely sensed or collateral data sources.

Landsat data was used in an automated classification procedure to produce vegetation type and density labels. Landsat data has been shown to be strongly related to the basic structure of vegetation (Woodcock et al., 1980). Thus, the vegetation types created in the Landsat classification are primarily physiognomic, or structural in nature. This physiognomic classification is expected to have significance for fire behavior because several of the characteristics identified as important for fire behavior are primarily structural. Branching habit and the size class distribution, though not specified by the physiognomic classes, should be significantly different between classes. The density component of the Landsat label can be used as an indication of the spatial contiguity of the vegetation cover.

The information available in the Landsat-based type and density classes can be enhanced by the use of collateral data. Fire history data can be used to provide live/dead ratio information. The live/dead ratio in chaparral vegetation is related to the age of the vegetation (Rothermel and Philpot, 1973). Using the time to the last burn as the age of the vegetation, another parameter identified as significantly influencing fire behavior can be obtained.

Field observation has indicated that there are subtle variations in several vegetation characteristics that are important for fire behavior within the Landsat-based vegetation type and density classes. This variation seems to be correlated with changes in the quality at the site for plant growth (Kittredge, 1939). Thus, a spatial ecological model predicting site quality could be used to reduce the effect of within class variation in burn characteristics of the Landsat-based classes.

3.1.4.1 Landsat Processing

Registration. The first step of the Landsat processing was to register a sub-image of the Landsat data to the digital elevation model (DEM) terrain data. The DEM data had an original spatial resolution of thirty meters, but was resampled to fifty meter grid cells. All data layers were resampled to fifty meters to match the grid cell size used by the FIRESCOPE project. The Landsat data was registered to the digital terrain data because the digital terrain data will eventually serve as the reference layer for the FIRESCOPE database. The Landsat data was registered to the terrain data through the use of ground control points and a rubber sheeting algorithm. A procedure was formulated to assist the difficult task of precisely locating ground control points on the terrain and Landsat images. Since the DEM terrain data was derived from orthophoto quadrangle maps, the orthophotoquad of the study area was put on a coordinate digitizing table and the four corners of the orthophoto quad. Ground control point location simply involved: finding corresponding points on the Landsat Band 5 image and the orthophotoquad; determining the Landsat line and sample of that point on an enlargement of the study area; and digitizing that same point on the orthophotoquad, whereby the coordinate values which were displayed on the digitizer were those of the DEM terrain file. These two sets of coordinates for each point were then used to precisely register the Landsat to the terrain data. The strong spectral correlation between the orthophotoquad and the Landsat Band 5 image greatly facilitated this procedure.

Texture. Following registration, a texture image was created from the Landsat Band 5 image. These two images are shown in Figures 1 and 2. Texture has been shown to enhance differentiation of natural vegetation types (Strahler et al., 1979). Texture has long been identified as a major source of information in manual image interpretation processes, and should also be included in automated classification procedures. The texture channel used in this project follows the suggestion of Logan et al. (1979). To create the texture image, a moving window of three-by-three picture elements (pixels) is passed over the image. For each three-by-three window the standard deviation of the nine brightness values is computed, scaled, and placed in the location of the center pixel. This value provides a quantitative measure of the local tonal variation, which aids the differentiation of vegetation types that have similar spectral responses but differing spatial occurrence patterns.

Past experience in manual interpretation of vegetation types in areas with Mediterranean climates had indicated that different types of chaparral generally have associated textures. Soft chaparral is typically very patchy and irregular in its spatial distribution, resulting in high texture values. Mixed chaparral is more homogeneous in spatial cover than soft chaparral, and could be associated with lower texture values.

The texture channel was included with the Landsat data as a pseudospectral one in the classification procedures. The Landsat and texture data were classified into vegetation type and density classes using an unsupervised classfiication approach first reported in Strahler et al. (1979). Unsupervised classification is particularly effective for natural vegetation classification due to the continuum of variation found in natural vegetation scenes.

Classification. The first step in the unsupervised classification procedure is clustering of the input data layers. In this step, common locations in spectral measurement are identified and stored as means and variances for future processing. These "clusters" are constrained to represent very small portions of measurement space. The underlying assumption of this procedure is that each cluster corresponds to only one vegetation type, and that some vegetation types may be comprised of several different clusters. Thus, a large number of spectral clusters are created that will eventually be merged and edited into a greatly reduced number of final classes. This approach also helps reduce the impact of differential illumination due to high topographic relief and low sun angle at the time of the Landsat overpass. Individual cover types that contain spectral variation due to illumination and reflection geometry, can be expressed as a large number of classes with low variance rather than a small number of classes with high variance. Even with this approach, however, confusions can still arise when different vegetation types have the same spectral signature due to changes in illumination and reflection geometry. This situation was minimized by use of a Landsat tape with a relatively high sun elevation, and was not found to be a significant problem in this project.

Following clustering of the image, the spectral classes must be edited into the final classes. This editing is accomplished in two phases, a spectral editing phase prior to the classification of the image, and a spatial-spectral editing phase following image classification. In the spectral editing phase, the spectral clusters are input to a complete linkage clustering algorithm that operates on a standardized distance matrix. In essence, this procedure amounts to "clustering the clusters" and produces a dendrogram of the classes. The dendrogram identifies spectral clusters that are similar and may be pooled with little risk that clusters corresponding to different vegetation types are being combined into the same cluster.

The clusters remaining after the spectral editing phase are used as input to a parallelepiped-maximum likelihood classifier. In the parallelepiped phase, "windows," measured as a user-specified number of standard deviations, are created around the means for each class. Each pixel is then compared to each cluster to see if the brightness value for each channel falls inside the windows for that cluster. There are three possible results for each pixel. If the pixel's brightness values do not fall through all of the windows for any one cluster, the pixel is designated as unclassified. If the pixel's brightness values fall through all the windows for any one cluster, then the pixel is assigned to the class number corresponding to that cluster. If the pixel's brightness values fall through the windows of two or more clusters, a maximum likelihood criterion is invoked to determine which cluster of the possible candidates the pixel is most likely to belong to.

The spatial-spectral editing phase of the classification involves aggregation of spectral classes into vegetation types. This task is accomplished through interactive viewing of spectral classes to determine their spatial contiguity and surface cover type. This step of the classification requires the most analyst input and, to a major degree, determines the quality of the final classification. In this step, the level of differentiation of classes is determined, and the spectral classes to be combined into a single vegetation type are identified.

During the spatial-spectral editing phase, it was noticed that the areas designated as unclassified were characterized by several different cover types. Thus, it was impossible to provide an appropriate label to the unclassified pixels, which comprised approximately four percent of the image. To alleviate this problem, a mask was created of zero's for classified areas and ones for unclassified. This mask and the raw spectral and texture data were multiplied, essentially eliminating the raw data in areas previously classified. Then, the modified spectral and texture data were processed according to the classification scheme just described. The result was the division of the previously unclassified pixels into several classes that could be labeled independently, and merged into the appropriate cover types. This approach allows the guarentee of full scene classification, which is very important for this application. In the fire spread computer simulation models, the fire has to spread through each pixel, so the burn characteristics of each pixel are important. This procedure could be applied to any original spectral class that was determined to include too wide a range of vegetation types.

The final Landsat-based classes are listed with their associated acreages in Table 1. There are twelve final classes that correspond to the differentiation of six vegetation types with three density distinctions for three of those types (see Figure 9). The density distinctions were removed to produce a more generalized classification map by aggregating the classes into the six vegetation types. The resulting classification map may be useful for fire management needs other than the computer simulation models. For example, this generalized vegetation map may be helpful to on-site firefighters in pre-attack planning.

3.1.4.2 Incorporating Collateral Data

Landsat-based classification is capable of providing basic vegetation type and density distinctions. These distinctions contain useful information concerning some of the characteristics of vegetation identified as important for fire behavior. However, processing of Landsat data alone

Table I. Acreage Summary for 12 Vegetation Type/Density Classes

Class	Pixels	Acres	Percent	Description
1	6900	4600	10.607	Mixed Chaparral/Low
2	11922	7948	18.327	Mixed Chaparral/Medium
3	4800	3200	7.379	Mixed Chaparral/High
4	3239	2159	4.979	Mixed Chaparral/High-w/Oaks/Medium
5	1783	1189	2.740	Mixed Chaparral/Med-w/Mixed Trees/Low
6	1437	958	2.209	Mixed Chaparral/High-w/Mixed Trees/High
7	3726	2484	5.728	Conifers/Medium
8	3602	2401	5.537	Soft Chaparral/High
9	13446	8964	20.670	Soft Chaparral/Medium
10	2354	1569	3.619	Soft Chaparral/Low
11	10597	7065	16.290	Grass
12	1246	830	1.915	Sparse/Barren

cannot be expected to provide information about all of the vegetation characteristics influencing fire behavior. Thus, to provide information about these other characteristics, collateral data sources must be used.

<u>Fire History</u>. One collateral data source that was used to enhance the Landsat-derived information was fire history maps. Fire history determines the time to the last burn of an area, and can be used as an estimate of the age of the vegetation. Chaparral species have fire adapted reproductive mechanisms, so most areas are revegetated in short periods of time following burns. The age of the vegetation is related to the proportion of the standing biomass that is dead, which is one factor that directly influences fire behavior. Thus, fire history maps for the study area were digitized and registered to the database. The digitized fire boundaries were processed to produce a digital image, where each pixel was assigned a value associated with the time to the last burn. The digital fire history is shown in Figure 3. Overlaying the fire history data on the Landsat-derived vegetation type and density classes allows further partitioning of those classes based on the age of the vegetation. Based on the significance of the live-to-dead

ratio in fire behavior, this simple procedure may significantly improve the quality of the information that can be provided.

Site Quality. In an attempt to provide information beyond the Landsat classification and fire history data, a site quality model is being developed through the use of several collateral data sources. The site quality model is expected to help within-class variation in total biomass of the Landsat vegetation type density classes. Within vegetation types there are subtle variations in growth rates that influence the accumulation of total biomass. Distinctions of this kind within vegetation types cannot be otained through the use of Landsat data alone, but may have significant impact on fire behavior. Total biomass can be partitioned into standing biomass and accumulated litter or duff. Both standing biomass and accumulated litter influence fire behavior and should increase with site quality. Site quality in the FIRESCOPE area is expected to be determined principally by water availability. Since water availability is influenced by a large number of factors, the site quality model requires the accumulation of many data layers. The attempt to develop a site quality model based on multiple input data layers shifts the research from being primarily a remote sensing application to a geographic information system application using remotely sensed data.

The first important step in the development of a site quality model is to accumulate data layers containing the variables that exhibit the primary effects on site quality. Since site quality is expected to be related primarily to water availability, the pertinent variables should explain the main factors influencing the local water budget. At the present time, the site quality model is still in the phase of demonstrating that the variables necessary for the model can be expressed in a spatial, digital manner and included in the database.

Precipitation data were obtained from the Angeles National Forest in the form of precipitation contours which were derived from rain gauge point samples. Variations in the data are primarily due to orographic effects. These data were digitized and registered to the database (see Figure 4) and each 50 meter pixel contained data regarding the inches of precipitation that occurred in the previous year. Since the site quality model is intended to produce information about a phenomenon that has occurred over a number of years, namely accumulation of biomass, the absolute magnitude of precipitation data is best viewed as a relative precipitation map. These data provide a baseline indication of the moisture available from precipitation. Modifications to this baseline data are effects resulting from slope form, soil types, and relative solar insolation.

Soils data were also obtained from the Angeles National Forest. Comprehensive soil descriptions had not been finalized by the USFS in time to be included in the final products of this paper. Only soil boundaries were labeled as such. For this reason, no detailed data were produced which relate areas within the boundaries to actual soil classes. Eventually, soil types could be aggregated according to their physical properties that influence water availability and included in the model as categorical treatment effects. The physical properties that are expected to affect water availability the most are depth and texture of the soil. Also, soil types may influence site qualities in ways unrelated to water availability. In particular, effects on biomass accumulation due to toxic soils may be included in the site quality model, outside the dominant water availability emphasis.

One important data layer for the water availability model is the relative solar insolation received at the individual picture elements in the area. Incident solar irradiance provides the energy for evapotranspiration, which is the main desiccating force in Mediterranean climates. Expected solar illumination can be calculated for individual picture elements, at any given day and time if the slope angle and aspect, and latitude and longitude are known. The slope angle and aspect data can be derived from the digital elevation model. A slope angle image is illustrated in Figure 6, and a shaded relief map, derived from the slope aspect image, is shown in Figure 7. The incident solar illumination can be integrated over a single day and summed for any number of days to provide a relative expected solar insolation image for a specified time period (Dozier, 1980). A solar illumination image for the study area is shown in Figure 8 for the time of the Landsat overpass which was used in this research.

Another factor that influences the water budget at a given point is the shape or form of the slope. Canyons, or coves which are concave in shape will accumulate water from overland flow and soil throughflow, while ridges lose water by these same processes. Thus, a topographic position (slope form) model is being developed, which measures the degree of curvature of a slope in two directions. In this model, a second order surface is fit to the elevation values for a three-by-three window surrounding each pixel using a least squares criterion. A primary axis is then established as the direction of most rapid change in the surface. The physical interpretation of this primary axis is the direction of the steepest slope from the center pixel either up or down the slope. A secondary axis is defined that is perpendicular to the primary axis and can be interpreted as the direction across the slope. The second derivative in the direction of each axis is computed and scaled for output. If the second derivative is positive in both directions, the point is at the top of a hill or on a ridge, and if it is negative in both directions, it is in a cove-shaped location, with all possible combinations between these two extremes.

The important step remaining in the development of the site quality model is to determine the relative magnitude of the influence on site quality, of the variables included in the database. There are two fundamental approaches to the solution of this problem. One approach is to weight the contribution of the variables according to some predetermined theoretical model. The other approach involves estimating the contribution of the variables through the use of field samples and regression techniques. In this approach, field samples that measure moisture availability for all ranges and combinations of the independent variables could be used in a multiple regression analysis. Measured water availability would serve as the dependent variable, while the resulting coefficients for the independent variables would determine their relative influence.

3.1.5 Conclusion

Landsat spectral data can be combined with a synthesized texture channel in an unsupervised classification procedure to provide a physiognomic vegetation classification. Although, originally developed for forested areas, use in a chaparral environment serves to further establish the viability of these techniques for natural vegetation classification. However, some vegetative characteristics that influence fire behavior vary significantly within the Landsat-based classes. In order to reduce this within-class variation, collateral data sources must be used. Fire history maps, when available, provide an easily used source of vegetation age data, which is an important factor influencing fire behavior. Another factor that varies significantly with vegetation classes is total biomass. Differences in local growth rates are due to variations in site quality and account for this within class variation in total biomass. Thus, a spatial site quality model could be used to explain that variation. Development of a site quality model requires two fundamental steps. The first step is to demonstrate that the main factors influencing site quality can be represented digitallly in a spatial manner. This step has been accomplished through the registration of precipitation, soil type, solar illumination, and slope form data. The second step, which requires further research, is the development of a model that specifies the magnitude of impact of the individual input data layers on site quality.

3.1.6 User Commitment

The results of this project have been very encouraging, and the Forest Service has substantiated this by requesting that UCSB/GRSU submit a proposal to the FIRESCOPE Program. We have been asked to propose a cooperative agreement between the USFS, the University of California at Santa Barbara, and the 257 cooperating agencies in the FIRESCOPE Program area to further the development of a fuels database for the FIRESCOPE Program area.

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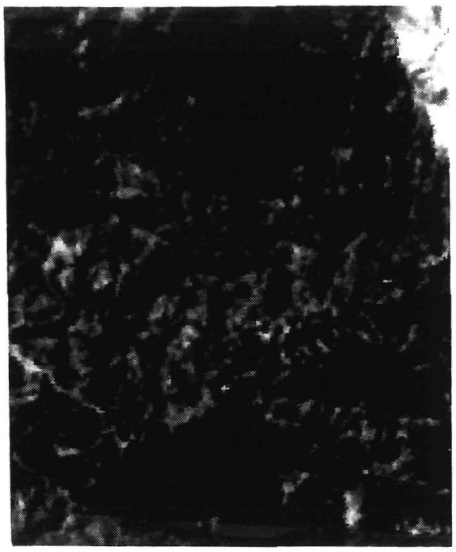


FIGURE 1. LANDSAT BAND 5 IMAGE.
This Band 5 image displays the Condor Peak 7.5 minute quadrangle study area. All other figures are registered to this area in 50 meter square pixels.

FIGURE 2. STANDARD DEVIATION IMAGE.
This "texture" image was derived from Landsat Band 5. It quantifies local tonal variations, where bright values depict spatial variability in spectral values. This image was also used in the classification process.

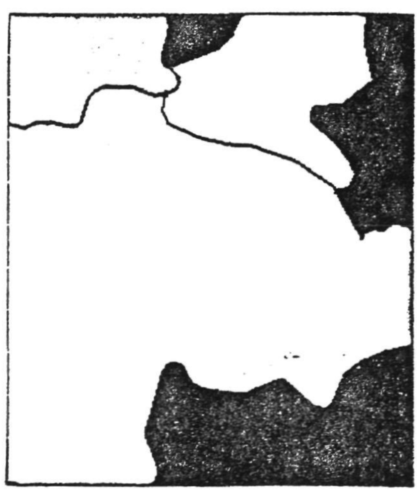


FIGURE 3. FIRE HISTORY IMAGE.
This digital image shows the time to the last fire. The data was digitized from U.S. Forest Service maps. Light values indicate more recent burns.

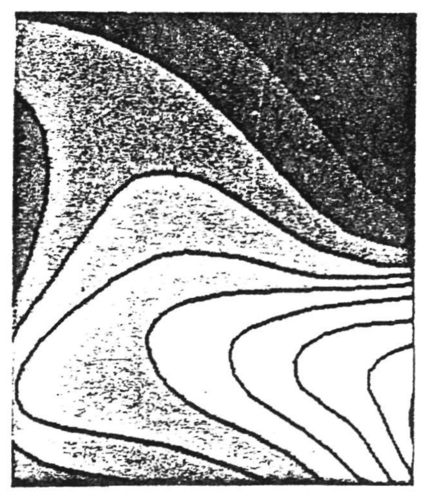


FIGURE 4. PRECIPITATION IMAGE.
This image was created by digitizing isohyetals derived from point source rain gauge data for a single year. It indicates relative rainfall patterns. Light values represent higher rainfall.

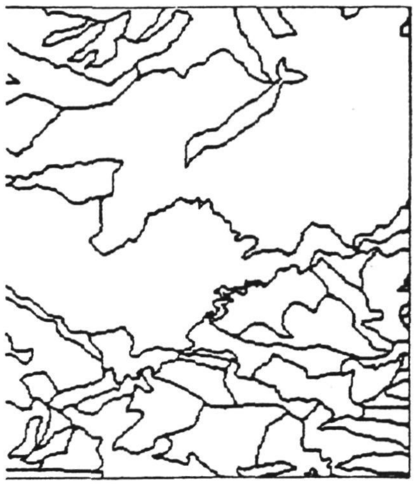


FIGURE 5. SOIL TYPE BOUNDARIES.
This image was digitized from USFS soil maps. When soil descriptions are finalized, grey values, corresponding to these descriptions, will be assigned to areas within the boundaries.

FIGURE 6. SLOPE ANGLE IMAGE.
This image was derived from digital elevation model (DEM) terrain data, which will serve as the reference layer in the FIRESCOPE database. Bright values indicate steep slopes.

FIGURE 7. SHADED RELIEF IMAGE.
This image was derived from the DEM terrain data. The image shows the area as if it were illuminated from the northwest at a 60 degree zenith angle (typical of shaded relief maps).

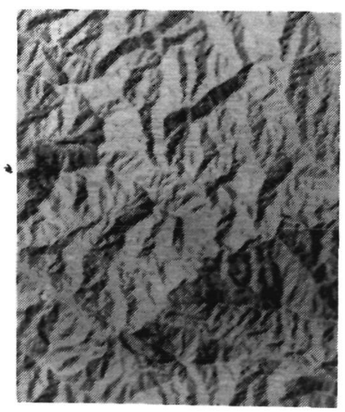
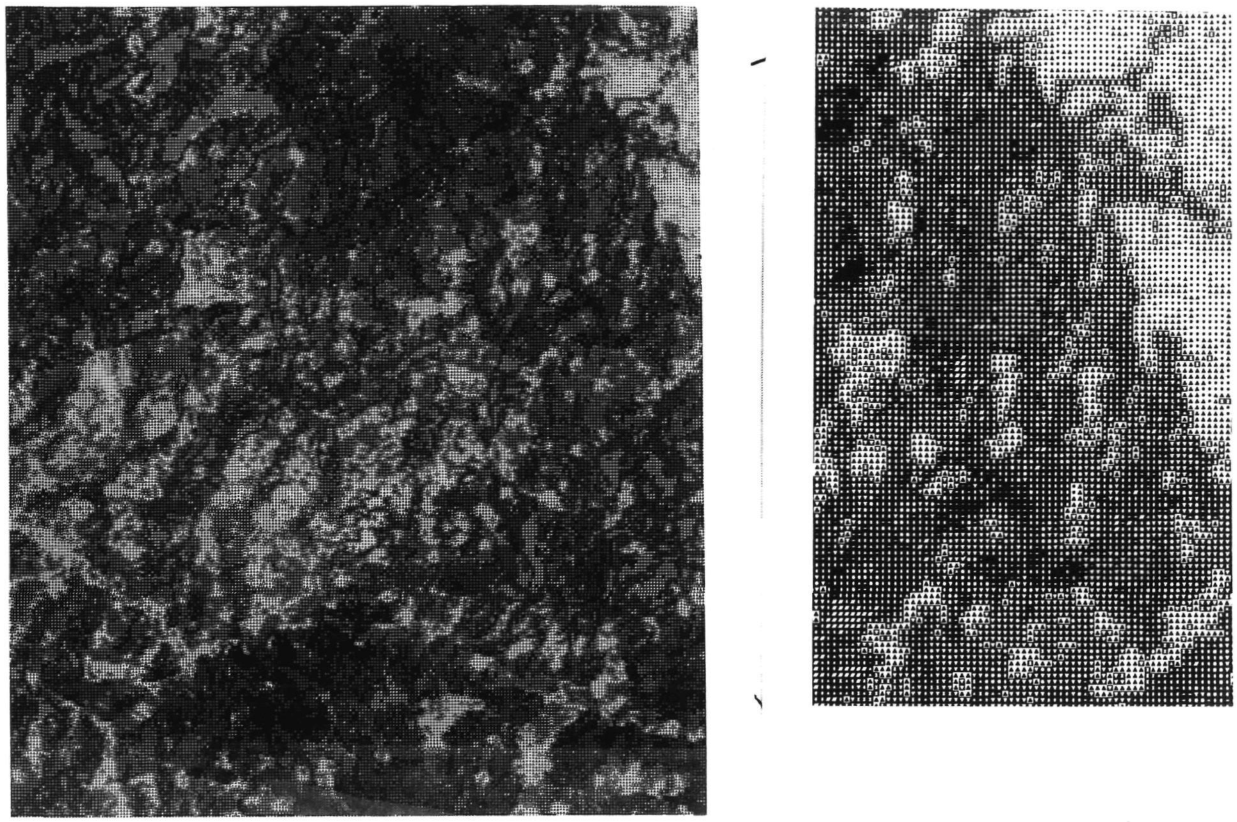


FIGURE 8. SOLAR ILLUMINATION IMAGE.
This image displays the expected incident irradiance at the time of the Landsat overpass. Note the strong relationship between this image and the Landsat Band 5 image.



= Mixed Chaparral/Low
= Mixed Chaparral/Medium
= Mixed Chaparral/High
= Mixed Chaparral/High-w/Oaks/Medium
= Mixed Chaparral/Med-w/Mixed Trees/Low
= Mixed Chaparral/High-w/Mixed Trees/High
= Conifers/Medium
= Soft Chaparral/High
= Soft Chaparral/Medium
= Soft Chaparral/Low
= Grass
= Sparse/barren

FIGURE 9. LANDSAT FUELS CLASSIFICATION OF CONDOR PEAK 7.5 MINUTE QUADRANGLE.

The spatial distribution of wildland fuels are depicted in this Landsat-based classification. Enlarged area shows individual 50 meter square pixels displayed as DN-symbols, and the legend identifies the associated vegetation type and density (relative crown closure). For use by firefighters, this classification was output at a scale of 1:24,000 in transparency form for overlay with orthophotoquads to allow for easy interpretation and navigation in the field.

Determining the Feasibility of Using Remote Sensing
Techniques to Detect Salinity Related
Cotton Canopy Reflectance Differences

by

Elaine Ezra

3.2.1 Objectives

The research described herein was designed to determine whether ground based _in situ_ hand-held spectral radiometer data (wavelengths coincident with the Landsat multispectral scanner; 0.4 - 1.1 μm) collected at near weekly intervals, can be used to make qualitative and/or quantitative assumptions about cotton grown under different salinity irrigation treatments. Measurements were collected from experimental plots located in Lost Hills, California, where on-going research is being conducted by the United States Salinity Laboratory, a branch of the U.S. Department of Agriculture based at Riverside, California.

Specific objectives included:

- Collection of hand-held spectral radiometer data on a bi-weekly basis throughout the cotton growing cycle (June-November) for each of six salinity irrigation treatments.
- Analysis of the data to determine whether there exists a significant difference in the reflectance characteristics of cotton grown under various salinity irrigation treatments, and, if so, attempt to quantify the relationship between salinity content and reflectance/emittance.

Analysis of the data includes graphical representations of reflectance/emittance values plotted against salinity content through time. Statistical correlation and regression analyses were also performed on the data.

3.2.2 Relevance

Soil salinity and associated drainage problems are becoming increasingly important issues in many arid agricultural environments throughout the world. The effects of these conditions result in reduced crop yields, and ultimately, the loss of highly productive lands. One such region of local concern is the southern San Joaquin Valley, California, where natural drainage is inadequate to maintain high productivity in many of its areas. Approximately 400,000 acres (160,000 hectares) of irrigated farmland in the San Joaquin Valley currently are affected by high brackish water tables that pose a serious threat to productivity. About 1.1 million acres (450,000 hectares) ultimately will become unproductive unless some type of management action is taken (San Joaquin Valley Interagency Drainage Program, 1979).

Present methods of detecting and monitoring soil salinity content and problem areas are based upon costly and time-consuming ground based soil sampling procedures. Remote sensing techniques offer the potential for improvement of present sampling techniques through stratification using vegetation and soil condition as surrogate measures of spatially variable salinity levels. Sampling based upon stratification should reduce the number of samples required, and thus, the associated costs. The preliminary steps towards developing a stratification methodology involves an understanding of the physical basis for interpretation of saline regions. This requires knowledge regarding the plant/soil interactions (how the plant responds to varying salinity concentrations) as well as the resultant spectral and thermal characteristics exhibited by vegetation experiencing different degrees of salinity stress.

It is becoming increasingly evident that accurate in situ ground based data collection is necessary for measuring vegetation characteristics. This is primarily to increase our understanding of the information available in the spectral reflectance and vegetation interaction. Hand-held radiometers offer the potential to adequately cover the spatial variability required for such a task. They are light and portable and, therefore, can be used to collect basic data about vegetated surfaces in a controlled experimental setting. Such data could increase the knowledge about remote sensing of soil salinity and remote sensing's potential role in improved information extraction. The <u>in situ</u> data should also discourage or prevent overly ambitious application of remote sensing where no causative relationship can be shown to exist for the particular task at hand within the limitations of the field measurement program employed (Tucker et al., 1979a). Thus, as a result of this research it should be possible to ascertain whether or not stratifying salinity affected areas in cotton fields based upon spectral reflectance measurements is indeed valid.

Although it appears possible to develop hand-held radiometry into a useful operational tool for agricultural purposes, the scale at which hand-held radiometry can be applied is small and labor intensive. Consequently, aircraft and satellite platforms will form an important element for large scale stratification operations. A major objective of this effort will be to test the potential to relate specific important agronomic parameters to spectral data in such a manner that the methodology can be extrapolated for use with data provided by aircraft and satellite systems.

The need for rapid and accurate salinity assessment techniques has been expressed by the U.S. Salinity Laboratory as an area of definite interest and concern (Suarez, 1980). Remote sensing techniques may be developed to provide information which can indicate where salinity problem areas exist, and where they are likely to develop. This data would be of benefit to individual farmers, as well as water resource planners at the local, state, and national levels.

3.2.3 Procedures and Expected Results

This experiment has entailed the collection of measurements taken with an Exotech Model 100A Landsat Ground Truth Radiometer, over thirty cotton fields grown under controlled salinity irrigation treatments. This radiometer is configured to measure the same spectral radiances as those presently found on Landsat series satellites 1, 2 and 3 (MSS 4, 5, 6, and 7). Hand-held radiometry is ideally suited to this experiment because of portability, and too, as the experimental plots are too small to be adequately analyzed from data typically acquired by high altitude aircraft or satellite based sensors.

By the year 2000, the Interagency Drainage Program predicts that facilities to dispose of 425,000 acre-feet of drainwater annually from the San Joaquin Valley will be used to alleviate rising water tables in the Valley trough (U.S. Salinity Laboratory, 1980). The U.S. Salinity Lab is currently conducting a continuing experiment to test the hypothesis that cotton can be profitably grown on a commercial scale with irrigation water of quality anticipated to be available as drainwater from Kern County farms. Controlled field trials, using variable irrigation management, have been set up to test this hypothesis.

The experimental site where these tests are being conducted is located approximately ten miles north of Lost Hills, California (T25N, R21E, S16) on property owned and operated by Riverwest Farms Inc. One reason for the selection of the location was that it is an area with soil conditions typical of those in which drainage problems are expected to arise within the basin. Another reason is that it was near a well which delivers the water quality typically anticipated to be available in the future as drainage water. The location is also adjacent to a canal carrying the California Aquaduct water.

Sixty 40 by 100 feet plots were layed out in two rows. The experimental plot layout and soil sample coding format is given in Figure 1. Pipes were installed at the beginning of the experiment to bring aqueduct water with an electrical conductivity of about 0.6 mmho/cm and well water with an electrical conductivity of approximately 9 mmho/cm a distance of one-half mile to a mixing station at the head of the plots. Additional pipes were installed to deliver either one or a mixture of the two waters to each of the plots. Because differential leaching quantities were applied as preirrigation, every plot received the same quantity of water at each irrigation during the growing season.

Three variables are being tested in the Salinity Laboratory's experiment: 1) irrigation water quality during germination; 2) irrigation water quality during the growing season; and, 3) maximum salinity at the bottom of the root zone. The treatment variable assigned to each plot is given in Table I. In the three letter designation, the first (either L or H) represent high or low leaching. The absolute value of the leaching fraction indicated by either L or H increases with increasing irrigation water salinity to achieve an approximately equal salinity at the bottom of the root zone. The second letter (either A, M, or W) represents the source of the six inch pre-irrigation made prior to germination whether aqueduct, well water, or a mixture. The third letter (A, M, or W) represents the source of the water used for irrigation during the growing season.

Instruments to measure soil salinity, soil water potential, water content, and soil temperature have been installed. Measurements of plant height, leaf number and area, numbers of flowers and bolls, leaf water potential and canopy width have been recorded and samples have been collected for determinations of lint weight and quality.

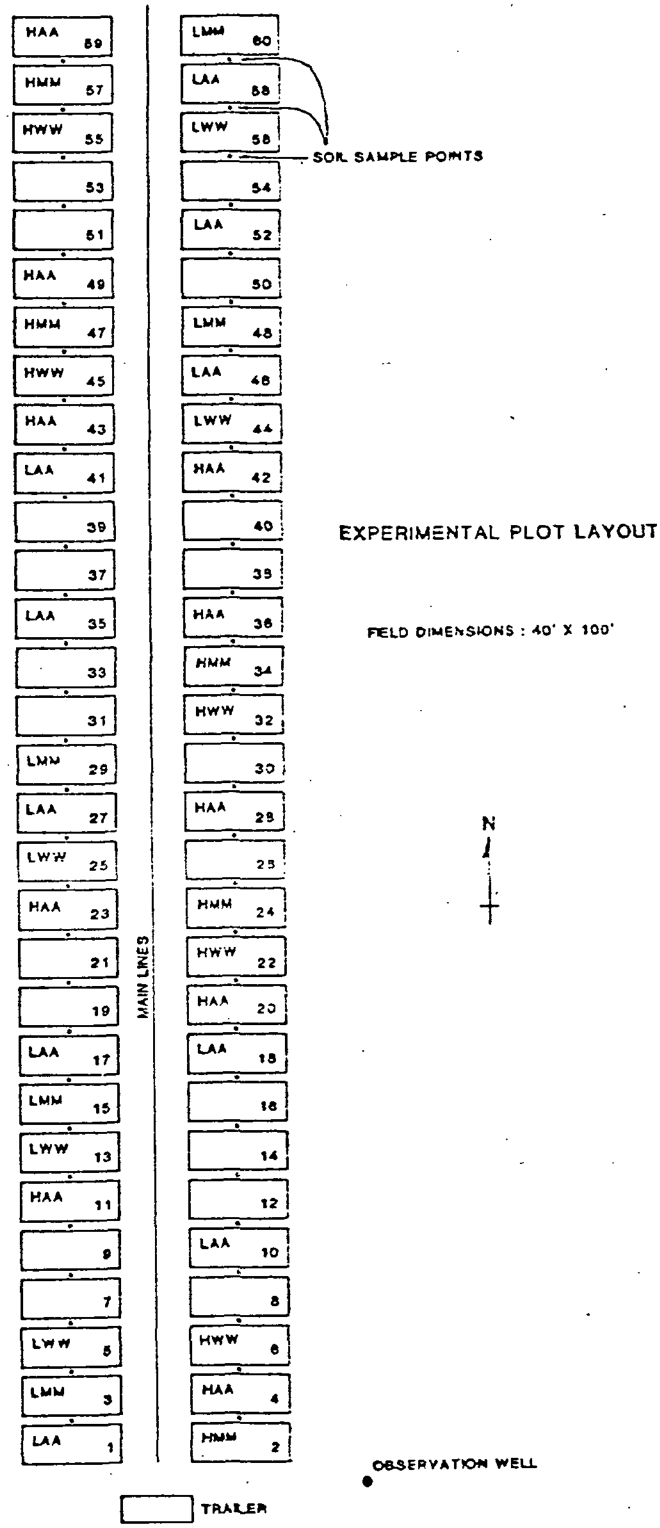


Figure 1. Experimental Plot Layout.

The objectives of this research are primarily concerned with the difference in spectral reflectances for the three salinity irrigation treatments: aqueduct, mixture, and well waters. Therefore, sampling will only occur in those fields in which both the pre-germination and crop growth irrigation treatments are the same. These treatments include: LAA, LMM, LWW, HAA, HMM, and HWW. With six irrigation treatments and five plots per treatment, there have been a total of thirty fields sampled. Each plot was sampled with measurements collected between 1000 and 1400 hours under sunny conditions; orienting the instrument in a plane facing the sun such that shadows cast by the observer or other sources were avoided. Edge effects were minimal due to the careful uniformity of irrigation procedures employed. The fields were planted with flat beds, and flood irrigation water applied to insure the homogeneous application and distribution of salinity. Measurements were collected from a truck-mounted plank which allowed for the radiometer to be held approximately 3 meters above the ground surface, and extend into the field approximately 3 meters.

The measurements taken in each of the plots included canopy radiance values in each of the four Landsat radiometer channels, incoming radiance values for each of the four channels by pointing the radiometer at the sun, away from the sun, and directly perpendicular. Reflectance values are being calculated using the ratio of incoming radiance to canopy reflectance values.

Agronomic data pertaining to crop development, such as the percentage crop cover, have been recorded through field notes and color and color-infrared photography. Ground based photographs also provide a means for documenting general growth stages, canopy architecture, and visual symp-

EXPERIMENTAL TREATMENTS BY PLOT

Leaching Fraction	Treatment Code: Water Quality Used During Pre-irrigation	Treatment Code: Water Quality Used During Irrigation	Plots in Treatment				
L 1/	A 2/	A 2/	1	17	27	46	58
L	M	M	3	15	29	48	60
L	W	W	5	13	25	44	56
L	A	A	35	41	10	18	52
H	A	A	43	59	4	20	36
H	M	M	47	57	2	24	34
H	W	W	45	55	6	22	32
H	A	A	11	23	49	28	42

1/ Leaching fraction (L=low; H=high); Aqueduct water (0.03, 0.15), Mixed water (0.08, 0.16), and Well water (0.15, 0.30)

2/ Irrigation water (A=aqueduct; M=mixed; W=well water)

TABLE I

toms of any type of disease or insect damage. Average plant heights have been measured on a grid; percent canpoy cover by visual estimates of the percent of ground covered by the leaf canopy. All agronomic variables were measured or estimated by the same observer throughout the study.

Initial results show a general trend of decreased reflectance with increasing salinity contents in the irrigation treatment. The relation between the reflectance and the factors which affect the magnitude of this property (salinity treatment, plant height, percent ground cover, etc.) is being investigated using multiple regression and correlation procedures.

This approach should closely monitor differences in cotton crop growth and development under varying salinity conditions. This information can then be used as a basis for determining whether there is a valid rationale for stratifying cotton fields based upon differences in spectral reflectance signatures for saline and non-saline conditions. It is anticipated that results from the analysis will be complete July 30, 1981.

3.2.4 Future Work

The U.S. Salinity Laboratory experiment is being conducted again this year (May-November, 1981). We are presently expecting to conduct additional field data collection efforts over this experimental test site. In addition to radiance measurements, we will collect thermal emittance data using a Teletemp thermal radiometer.

Thermal infrared techniques also offer a potential in the assessment of soil salinity. Saline soils tend to experience reduced thermodynamic activity; thus, the soil water is less available for plant use. Therefore, the plant's transpiration rate is reduced (Ehlig et al., 1963). In addition to moisture stress symptoms, plants grown in saline soils are generally retarded. Plants that suffer from moisture stress exhibit higher leaf temperatures than those with an ample and readily available water supply (Tanner, 1963).

An aerial thermal infrared survey conducted by Bartholic et al. (1972) over cotton plots grown with a wide range of plant water stresses illustrates the potential temperature differences that could be expected for crop canopies. The observed irradiances corresponded to cotton plant temperature differences up to 6°C between the most and least water stressed plants. The proposed research offers a unique potential to assess the thermal characteristics for a cotton canopy grown under different salinity irrigation treatments in a controlled environment through an entire crop growth cycle.

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CHAPTER 4

SOUTHERN CALIFORNIA STUDIES

Remote Sensing Applied to Problems of the California Avocado Industry and Improvement of California Crop and Livestock Reporting Service Fruit and Nut Crop Surveys

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CHAPTER 4

SOUTHERN CALIFORNIA STUDIES

1.0 INTRODUCTION

1.1 SUMMARY

During the current grant year the Riverside Campus investigators have been concentrating on the completion of the study for developing remote sensing techniques to provide improved methods for obtaining avocado crop acreage data. The techniques are also proving useful in providing cost-effective surveys for the entire California Fruit and Nut Crop Inventory. This is the third and final year for the avocado project, which has been jointly funded by NASA and the California Avocado Commission. The methods developed in San Diego County have been improved and are being tested in Ventura County, with final testing to be accomplished in Santa Barbara and Riverside Counties.

Completion of the research in San Diego and Ventura Counties show that these two counties contain 72 percent of the total avocado acreage in California. Table I shows the UCR estimates of bearing and non-bearing acreage for the two counties completed and the latest California Crop and Livestock Reporting Service (CRS) estimates for the other counties in California. The total acreage of 71,137 acres exceeds the latest CRS total by 15,685 acres! Most of the discrepancy has occurred in San Diego County. Reasons for the large error in CRS data are given in section 3.0. The investigation of the other five major counties is expected to be completed by June 30, 1981 under the joint funding provided by the California Avocado Commission.

Future work by the Riverside Campus group will include participation with California Department of Food and Agriculture statisticians (CRS) in the adaptation of the techniques developed for the avocado project to the quintennial Fruit and Nut Crop Acreage Surveys. The success on the avocado project has led to this request for a joint research and testing effort to help the CRS obtain a more cost-effective survey methodology.

1.2 OBJECTIVES

The primary objective of the project has not been changed since its inception. However, there have been considerable changes in the approach as the investigation has proceeded. The research has been oriented toward the development of techniques that would produce avocado acreage inventories more efficiently, more rapidly, and with greater accuracy. This objective included the establishment of an inventory of the number of acres of each variety and the year of planting of each block. As the research progressed it was found that remote sensing techniques were the only method that would permit the detection of many inaccessable acres of avocados, especially in northern San Diego County. However, it soon became apparent that determination of the age and variety of avocados by use of remote sensing data was not impossible, but would be extremely costly. The sequence of tasks has evolved to the following:

1. Detect and map the location of avocado parcels by remote sensing techniques.
2. Determine the County Assessor's Parcel Number (APN) for the grove or ranch from public records.
3. Establish a list of grove or ranch owners from existing public records.

4. Establish the variety and age of each block of avocados by contact with grower (or manager) through mail survey, telephone, and if necessary personal contact.

1.3 THE NATURE OF THE PROBLEM

A clearer picture of the problems that originally led to the study has emerged as the investigation has unfolded. By 1978 the industry began to realize the problems being caused by the planting of 5,000 additional acres of avocado annually since 1972. The statistics provided by the normal reporting agencies became suspect. Why couldn't the California Crop and Livestock Reporting Service (CRS) maintain accurate records? The following facts provide some explanation. The CRS schedules complete Fruit and Nut Crop acreage surveys for each county every 5 years. The CRS is dependent on County Agricultural Commissioners to provide updating information during the interim years. The failure in the system is two-fold. The state provides only $100,000 annually to perform Fruit and Nut Crop Acreage Surveys for the 58 counties. Last year it required $70,000 to conduct the survey in Tulare County utilizing the traditional field survey methods. Simple mathematics show that 5 year surveys are now impossible. The reliability of updated information from the County Agricultural Commissioners depends upon the emphasis placed on agricultural surveys by each of the counties.

In San Diego County it is apparent, for whatever reasons, that agricultural surveys are a low priority item. Unfortunately for the avocado industry, San Diego County contains half of the state's avocado acreage. If San Diego County statistics are unreliable, what about the other counties? Preliminary results in Ventura, Riverside, Orange, and Tulare Counties indicate that the reported avocado acreage data is approximately correct. While the current research project may provide a short-term answer in the form of more accurate statistics, the larger problem in San Diego County will require a long-term solution.

2.0 STUDY AREA

The major avocado growing areas in California occur in the southern coastal counties and the Central Valley eastern foothill counties of Tulare, Fresno, and Kern. Figure 1 indicates the southern counties, which contain avocado growing areas along the coastal plains, valleys, and plateaus. With the exception of the Central Valley counties, the local climates are mitigated by coastal influences. These influences, which reach 10 to 20 miles inland, reduce the extreme effects of most severe winter cold waves. Killing frosts along the coast are rare, although temperatures will dip to the low 20's (degrees Fahrenheit) on two or three nights during the winter. Likewise the extreme summer temperatures are moderated by the afternoon sea breezes.

Our studies this past year have concentrated on Ventura County, located 60 miles northwest of the city of Los Angeles. In Ventura County the avocados are again primarily planted upslope of the valleys and most recently have appeared on the Rincon Plateau overlooking the Pacific Ocean and the Channel Islands as well as neighboring oil wells. Figure 2 shows the various local growing regions in Ventura County. The early plantings were made in the Santa Clara River Valley on the south-facing slopes north of the river from Saticoy to Fillmore. Landsat imagery (Figure 4) provides an easy method of distinguishing the avocado groves

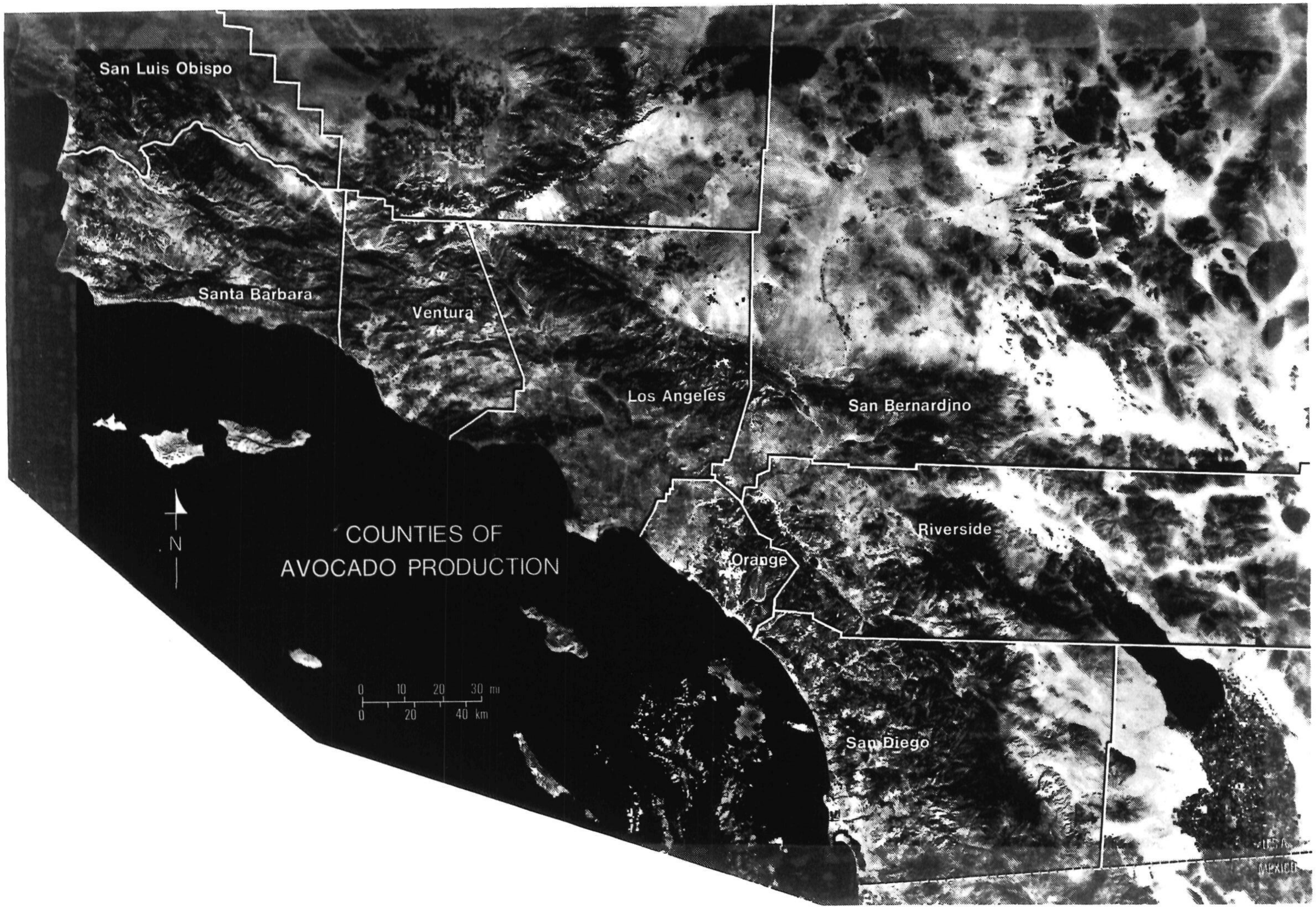

Figure 1. Southern California Counties that contain avocado producing areas. Avocados are grown primarily on the coastal plains and plateaus no more than 50 miles inland. Avocado acreage is expanding in San Diego and Ventura Counties and the southwestern area of Santa Barbara County along the Channel Coast. Urban encroachment has nearly eliminated avocado production in Los Angeles County. Avocado production has never been very large in San Bernardino County. Not shown is Tulare County in the Central Valley where large plantings of avocado trees are being developed.

on the higher slopes of the valley from the citrus grown on the lower slopes and valley flood plains. Another area of recent large-scale development has been the lower Simi Valley from Camarillo to Moorpark. The ideal climatic conditions in this area have enabled the area to become the most intensive avocado development in the county, perhaps in the entire state.

3.0 DISCUSSION OF RESULTS

3.1 SUMMARY OF RESULTS

Now that over 70% of the avocado acreage in California has been detected by means of remote sensing techniques, it is possible to make preliminary estimates of the total acreage. Obviously, these estimates will not be final until we complete the entire survey in June 1981. The avocado acreage that we have detected in San Diego and Ventura Counties from satellite, high-altitude, and low-altitude imagery is indicated in Table I. To arrive at a preliminary state total we have added our results to the latest CRS reported acreage for the remaining counties. The statewide avocado total -- 71,282 acres -- exceeds the CRS estimate for December 1979 of 51,995 acres by 37%! This increase raises the immediate question: How valid are the results from remote sensing? If the results are basically correct, then the increased acreage should be reflected in the current production output and the Avocado Commission should be vigorously pursuing all possible marketing techniques to increase domestic sales and open new foreign markets.

An inquiry to the Avocado Commission confirmed that greater-than-anticipated avocado production is occurring and that they are augmenting their marketing efforts so that all fruit will be marketed with at least

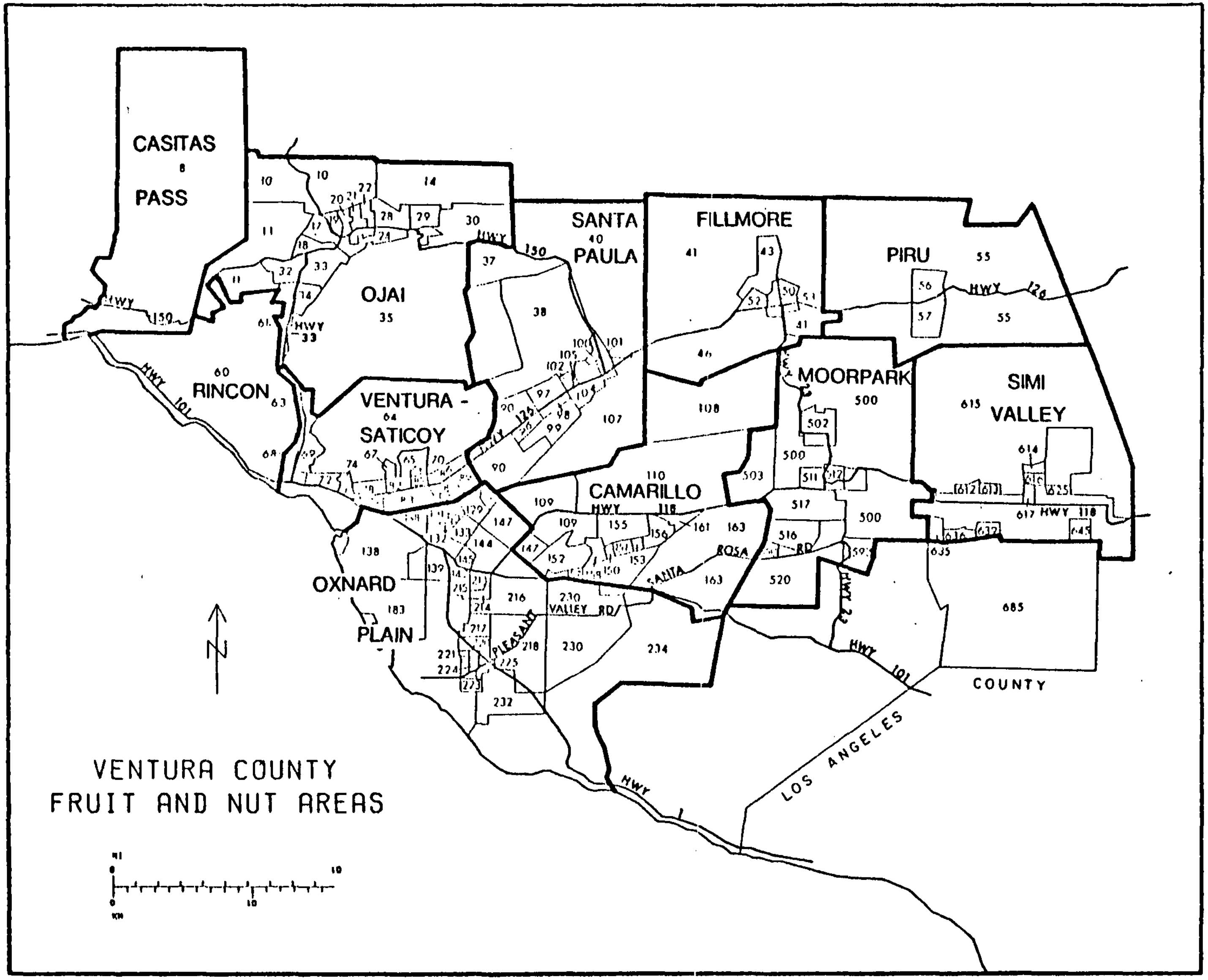

Figure 2. A map showing the various avocado growing regions in Ventura County. A comparison of this map with Figure 3 will indicate the predominant avocado production areas. Santa Paula, Fillmore, Camarillo and Moorpark are the traditional avocado-citrus production areas. Developers have recently concentrated their new plantings in the Camarillo area and subsequently have subdivided large parcels into 20 acre lots for sale to non-professional growers. Rincon Plateau and Casitus Pass are areas that have experienced recent heavy development of avocado acreage.

Table I. ESTIMATED CALIFORNIA AVOCADO ACREAGE
(by County as of July 1980)

COUNTY	DATA SOURCE[1]	BEARING ACRES	NON-BEARING ACRES	TOTAL ACRES	% OF TOTAL
SAN DIEGO	UCR	27,145 (est)[2]	10,000 (est)	37,145 (est)[2]	52.2%
VENTURA	UCR	12,000	2,450	14,450	20.3
RIVERSIDE	CRS	4,787	2,814	7,601	10.7
SANTA BARBARA	CRS	4,784	1,072	5,856	8.2
TULARE	CRS	1,263	623	1,886	2.7
ORANGE	CRS	1,002	685	1,687	2.4
SAN LUIS OBISPO	CRS	733	240	973	1.4
LOS ANGELES	CRS	985		985	1.4
OTHER[4]	CRS	620	79	699	1.0
TOTALS		53,319	17,963	71,282	100.1

1. UCR source is is data derived from the current University of California (UCR) Department of Earth Sciences Avocado Acreage Survey Research. The CRS source is data from the 1979 California Fruit and Nut Acreage Report dated June 1980 published by the California Crop and Livestock Reporting Service.

2. The San Diego County estimate for July 1980 is based on the UCR data derived from the August 1979 survey results which indicated a total of 34,820 acres. One year's average increase has been added to the 1979 total to yield the 1980 estimate).

3. The CRS published data utilized above represents estimates as of December 1979. Therefore the actual totals as of July 1980 are greater (no more than 1,000 acres) than the total shown above.

4. OTHER counties include: Fresno, Kern, Madera, San Benito, San Bernardino, Santa Clara, Santa Cruz, and Stanislaus.

a break-even price to the grower. When we notified the Commission last summer that the San Diego county acreage was approximately 20% greater than their estimate they did increase their production forecast by 12% from 340 million pounds of fruit to 380 million pounds. As the season has progressed, the forecast has been increased to an official 441 million pounds. Unofficially, some production people are suggesting as much as 500 million pounds of avocados will be produced and marketed by the end of the season on October 31, 1981. Increased acreage accounts for a large part of the increase, but the favorable climate during the growing season also accounts for some of the increase. However, climatic factors were considered in the original Commission estimate. Therefore, the low forecast figures can primarily be attributed to the 20% underestimate of the total avocado acreage. The increased production figures are not sufficient in themselves to prove that our remote sensing techniques are accurate. A comparison with past inventory history may be helpful in determining the validity of results.

3.2 COMPARISON OF RESULTS FOR SAN DIEGO AND VENTURA COUNTIES

To help determine the validity of the statistics derived from the remote sensing data, annual growth rates of avocado acreages for San Diego and Ventura Counties are presented in Table II.

The 1980 avocado acreage detected by remote sensing techniques in Ventura County is in accord with the annual growth trend for the past 10 years. In discussing the results with us, the Ventura County Farm Advisor and the CRS personnel have indicated that the Ventura County Agricultural Commissioner has been very careful to report changes in the crop inventory, and that they are confident in our remote sensing data.

Table II. ANNUAL GROWTH RATES OF AVOCADO ACREAGE

		SAN DIEGO COUNTY			VENTURA COUNTY		
Year	Total Acres	Acres	% of Total	Annual Increase	Acres	% of Total	Annual Increase
1955	23,163	13,712	59.2%		2,179	9.4%	
1960	24,423	13,616	55.8	- 20	2,927	12.0	150
1965	21,079	11,981	56.8	- 346	2,720	12.9	- 40
1970	22,940	12,920	56.3	188	3,460	15.0	150
1976	44,156	19,815	44.9	1,150	9,877	22.4	1,070
1977	47,859	20,910	43.7	1,095	10,863	22.7	986
1978	51,137	21,967	43.0	1,057	12,000	23.5	1,137
1979	51,995	22,841	43.9	874	12,924	24.9	929
1980	71,282	37,145	52.2	12,102	14,450	20.3	1,526

The CRS will contact each of the growers for the parcels we have identified to determine the age, number, and variety of avocado trees that they have in production. This will provide a near 100% verification and determination of error for the study in Ventura County.

The last actual survey of avocado acreage in San Diego County was conducted in 1972. Since that time the acreage has been estimated by the County Agricultural Commissioner. It is the opinion of the Farm Advisor, the packing house owners, and the Avocado Commission that the average annual increase in avocado acreage has been grossly underestimated. The Deputy County Agricultural Commissioner for San Diego County has stated to us that the county has not had sufficient monies to maintain accurate records for any fruit and nut crop acreage including avocados. Therefore, he will not claim any accuracy for their records. To comply with state reporting requirements the Agricultural Commissioner's office obtained our 1980 estimate of the avocado acreage in San Diego County and reported this to the CRS as their estimate. This does not make our results any more accurate; however, it does show that the historical reported growth rates in avocado acreage in San Diego County are not correct. It appears that the increase shown for San Diego County over the past eight years is unrealistically low. A statistical random sample analysis needs to be undertaken in San Diego County to verify the accuracy of the study. Our study for the next grant year will be in cooperation with the CRS; a result of that investigation will be an owner-by-owner survey by the CRS to obtain varietal information so that an even more accurate survey of San Diego can be accomplished.

Lacking a statistically valid analysis of possible errors in our research data, we can only point to the apparent accuracy of our work in

Ventura County, the obviously incorrect data supplied by the San Diego County Agricultural Commissioner, and most importantly the unaccounted-for increase in the current production to verify that our remote sensing procedures have resulted in a more accurate survey.

The remote sensing techniques developed for the avocado survey in San Diego County were tested this past year in Ventura County. A summarization of the data is shown in Table III. The significance of the data is better understood when the distribution of the parcels by acreage size is compared with the distribution of San Diego County data. In San Diego County 58% of the parcels are five acres or less, while in Ventura County only 50% of the parcels are less than five acres. The small parcels in San Diego County result from the historic development of avocado growing by the small, part-time farmer and the increased development of small parcels by people planning retirement who want a small avocado grove to supplement their retirement income. Less than 1% of the parcels in San Diego County are over 100 acres compared to 7.6% in Ventura County. The statistics show that in San Diego County avocado growing is still a small-farmer industry while in Ventura County it has become "agri-business" involving large corporations. One consequence is that a county such as Ventura or Tulare can be surveyed by remote sensing techniques and the data be verified much faster than in San Diego County. Some of the small parcels in San Diego County are only one-half acre with a house, swimming pool, and perhaps 25 trees. Figure 3 shows the distribution of avocado acreage by our second-level mapping unit, County Assessor's books. The results support our earlier statements regarding

Table III. SUMMARY STATISTICS FOR VENTURA COUNTY, CALIFORNIA AVOCADO ACREAGE (as of July 15, 1980)

REGION*	NUMBER OF PARCELS	TOTAL GROSS AC	AVERAGE GROSS AC	AVG % AVOCADO	AVG NET AVO AC	TOTAL NET AVO AC
CASITAS PASS	46	2,235	48.6	46.8	16.0	737
RINCON PLATEAU	12	1,127	93.9	23.3	35.8	429
OJAI	169	3,746	13.3	30.7	6.8	1,150
VENTURA-SATICOY	90	2,400	21.3	45.6	12.3	1,094
SANTA PAULA	196	9,386	31.3	29.0	14.7	2,886
FILLMORE	111	6,091	28.7	30.7	16.9	1,870
PIRU	33	1,368	17.8	28.5	11.8	390
OXNARD PLAIN	32	1,125	10.7	30.5	10.6	252
CAMARILLO	724	6,529	15.6	56.9	5.3	3,715
MOORPARK	170	4,012	13.5	49.4	11.7	1,925
UPPER SIMI VALLEY	3	9	0.5	43.3	1.0	2
TOTAL	1,586	38,028	24.0	38.2	9.1	14,450

(* Regions are grouped by topography, land use, and assessor's book criteria. See Figure 2 for a map of the regions.)

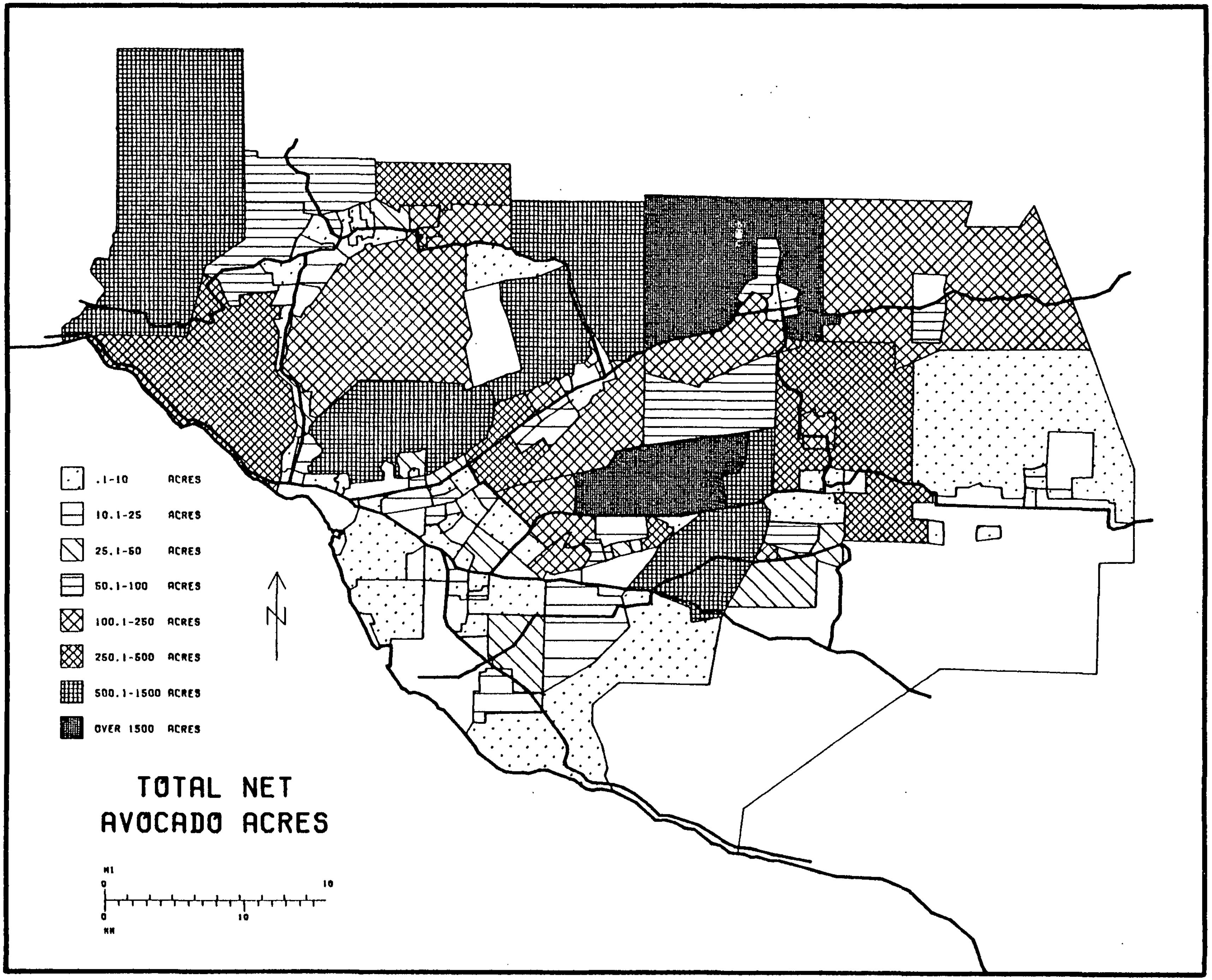

Figure 3. A map of Ventura County showing the total net acres produced in each Assessor's Tax Book. A comparison of this map with Figure 2 shows the predominant avocado production areas.

the study area. The predominant growing areas are the Santa Clara River Valley, Camarillo area, Moorpark, and Ojai. However, new ranches are being developed in Casitas Pass and on the Rincon Plateau; these two areas will become more important in the future.

3.3 AN INTERPRETATION PROBLEM

An interpretation problem that affects the final accuracy of our results has been the difficulty in identifying mature avocado trees as distinguished from mature Valencia orange trees. The primary feature in distinguishing avocado trees from citrus trees has been the natural color distinction. In most cases the citrus color is a much lighter tone or shade of green -- lemons are almost chartreuse on the imagery -- than the much darker tone of avocados. However, the mature Valencia orange tree has the same color as avocado trees. This requires the interpreter to seek other identifying features. The planting pattern is usually the other most distinguishing feature between citrus and avocado groves. Avocado trees usually are planted in a square pattern approximately 22 feet on a side. Citrus is most often planted in rows 20-24 feet apart and 11 feet between trees within the row -- about half the spacing of avocado planting. We have found that many Valencia groves have been planted in the same square pattern as avocados so that this identifying feature is also lost. The next feature for distinguishing avocado trees from Valencias is the scraggly appearance, viewed from above, of the crown and the resulting shadow on the ground. Most citrus appears as a uniform surface in a tight ball, whereas avocado trees support branches in many configurations. The Valencia trees are usually kept trimmed and rounded, but there is at least one time during the season that we have seen the Valencias in a sprouting stage which presents an appearance in its shadow closely resembling an avocado tree. It is at this time of year that it is most difficult to distinguish between the two trees. Consequently an error in interpretation can occur between these two crops. Hopefully, the errors are in both directions and will offset each other. The final resolution of these errors will be made when each grower is contacted for a listing of his crop varieties.

4.0 THE ROLE OF LANDSAT AND U-2 IMAGERY

For remote sensing of avocado acreage to be a cost-effective method of avocado inventory it is essential that all imagery platform levels be utilized for their unique capabilities. LANDSAT imagery was used for the initial identification of regions of agriculture and avocado production. U-2 and low-altitude imagery was utilized after candidate regions were located via LANDSAT. The actual avocado parcel inventory was accomplished by using the low-altitude natural color transparencies. Once the inventory is complete, future LANDSAT imagery will be used for locating deletions and additions to the 1980 base data.

In the process of utilizing LANDSAT for the avocado inventory, several inherent limitations of LANDSAT became apparent. Early fall imagery proved to be the most useful in highlighting agricultural areas. During the other moisture-surplus seasons, native chaparral is robust and highly reflective in the infrared wavelengths (bands 6, 7). By early fall the dessicated chaparral no longer blends with the adjacent agricultural plots on the imagery, thereby allowing the segregation of crops from natural vegetation.

Once the chaparral was eliminated, the frequently cited problem of pixel resolution became the next limitation. Characteristically, the size of avocado and citrus groves in San Diego County is less than the 1.1 acre optical and 4.4 acre sampling resolution of LANDSAT. And since avocado and citrus trees are interspersed throughout the northern part of the county, only a generalized tree crop classification was used to delineate potential avocado acreage.

In Ventura County, LANDSAT's resolution was adequate for accurately identifying avocado versus citrus parcels due to larger parcel sizes and their spatial segregation (see Figure 4). Avocado groves in Ventura County are most common on southfacing foothills, whereas the greatest concentrations of citrus are on the river bottom lands and the Oxnard Plain. In areas of mixed parcels mature avocado trees have a consistently brighter infrared return than citrus and are therefore separable during classification. Field crops and deciduous tree crops are eliminated in the LANDSAT classification procedure on the basis of seasonally varying returns on sequential LANDSAT scenes.

The highest classification accuracy was possible only in large parcels containing mature (bearing) avocado or citrus trees. This is because the bare soil between seedlings and non-bearing trees may lead to the interpretation of some parcels as fallow or bare land.

Presence of avocado groves through LANDSAT interpretation was verified by superimposing several U-2 images on multi-date LANDSAT scenes via a Zoom Transfer Scope. For large (5 acre) mature avocado groves, the LANDSAT interpretations were generally accurate and easy to make. New or non-bearing groves were not readily identified on LANDSAT, nor were they distinguishable on U-2.

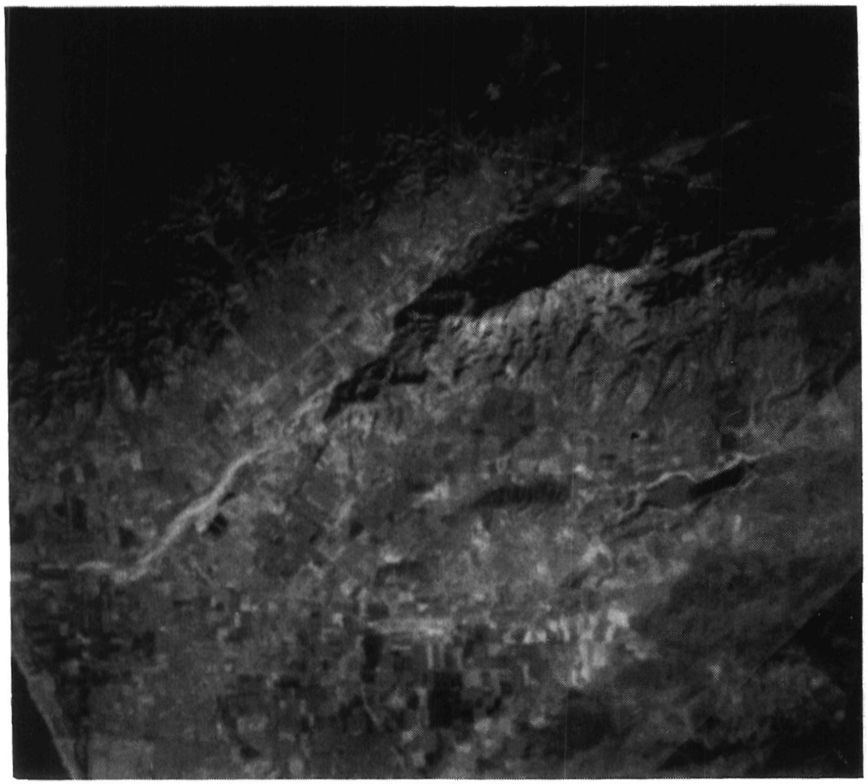

Figure 4a. Color-combined LANDSAT image of Ventura County. The large bright red areas along the upper valley slopes of the Santa Clara River Valley (dry river bed in center) are avocado trees. The dark red on the lower slopes and in the valleys distinguishes the citrus trees from the brighter avocado trees. In this image golf courses have the same spectral response as the avocado trees.

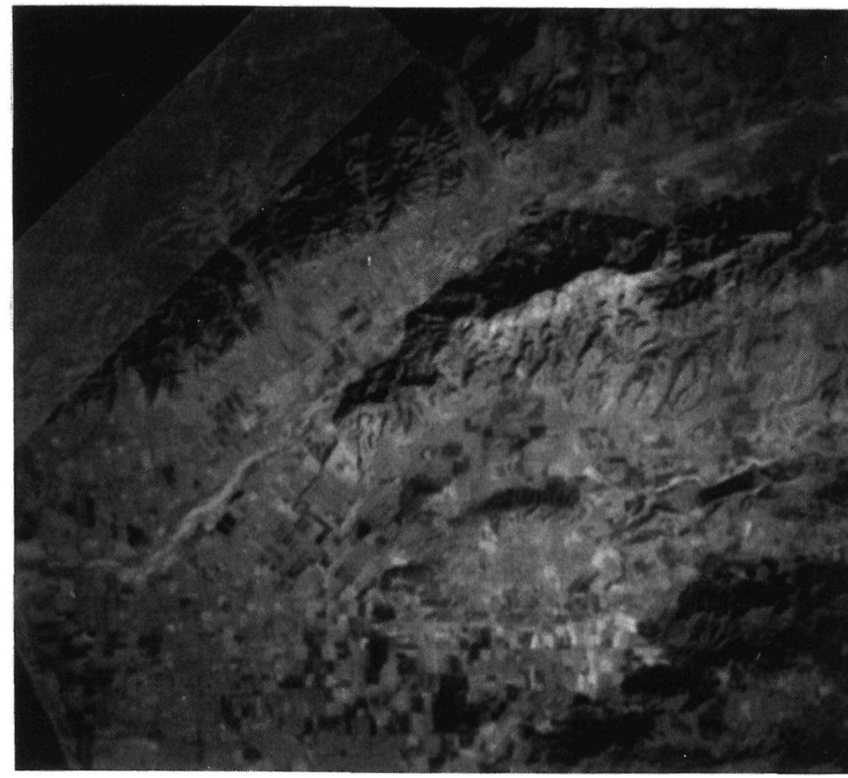

Figure 4b. Color-enhanced LANDSAT image of Ventura County. The avocado trees have now been falsely colored a yellow tint which enables greater distinction from the still darker yellow of the citrus trees.

The multi-date LANDSAT coverage of southern California is more comprehensive than the U-2 coverage available from NASA. Therefore, of LANDSAT-derived avocado regions were mapped and segmented into flight-lines which were flown at low altitude for complete large-scale (1:12,000) coverage of avocado-producing areas. Considering the exacting specifications of the avocado inventory, LANDSAT was useful in locating mature groves, but not adequate for highly detailed parcel mapping and the inclusion of immature groves. The task and exponential cost of saturated low-altitude coverage of possible avocado production areas was significantly reduced by using LANDSAT for initial identification of areas of interest.

The utility of LANDSAT for identifying <u>all</u> ages and sizes of avocado groves is beyond the sensor's inherent capabilities. The shortcut that a generalized LANDSAT classification provided has been an important step in focusing upon avocado production areas with subsequent higher resolution sensors.

Since the baseline inventory of avocado production is almost complete it is now possible to rely upon LANDSAT for monitoring future changes through several methods:

1) Pixels (digital data) and groves (LANDSAT photo data) which contain avocados in 1981 can be relocated in future LANDSAT data and evaluated as to whether the characteristic avocado tree signature is still present. Absence of the high infrared reflectance would indicate severe disease (and loss of production) or grove removal. Residential development, for example in the Santa Clara River Valley, commonly replaces avocado and citrus groves.

2) Land which was formerly chaparral and subsequently has been cleared constitutes potential regions for new avocado plantings. In Riverside County in 1974, large areas of chaparral were cleared in preparation of a large avocado low-density residential development project called Rancho California. The objective of such a large-scale reclamation of chaparral was not apparent in the LANDSAT imagery. However the bright appearance in the LANDSAT imagery drew our attention. Subsequent field checks revealed the purpose and identity of the development.

Similar chaparral-to-avocado grove conversion has been apparent via LANDSAT in San Diego, Ventura, and Santa Barbara Counties. Future LANDSAT monitoring of these conversions will demonstrate a shift in the reflectance data from a high visible-to-IR ratio (bare soil) to low year-round visible-to-IR ratio as the avocado crop matures. So far this process has been observed in multi-date LANDSAT imagery (1974-1980) covering Rancho California and is expected to be applicable to other areas of avocado grove development.

3) Agricultural parcels which contain annual or seasonal (and therefore non-avocado) crops in 1980 LANDSAT data may eventually be planted with a perennial crop such as avocado or citrus trees. These evergreen groves will not be detected until they mature. But the comparison of cyclic chlorophyl reflectance (annual/seasonal crops), followed by several years of fallow appearance (high visible-to-IR ratio) and ultimately by a perennial crop will serve as a signal for LANDSAT analysis and field enumerations.

5.0 PROJECT COMPLETION

The project is targeted for completion by June 30, 1981. The concluding activity will involve testing the procedures in the remaining Southern California counties. The counties with estimated acreages are: Riverside (10,000 -), Santa Barbara (8,000 +), San Luis Obispo (1,000), Los Angeles (900 -). In addition, Tulare County data will be obtained from the records of the Crop Reporting Service since they completed a parallel survey of that county in 1980. Eight other counties with less than 500 acres each, for a total of about 700 acres, will not be surveyed by remote sensing. The data will be obtained from the Crop Reporting Service. The two largest counties remaining (Santa Barbara and Riverside) are more than half completed at this date.

When a complete growers list is obtained as a result of this project, the list will be forwarded to the Avocado Commission for comparison with their lists. It was previously intended that a joint mail survey would be conducted to obtain the detailed varietal data (age, variety, and number of trees). However, since the CRS is now cooperating in the study, it is going to perform a personal grower interview in both Ventura and San Diego Counties during 1981. (It has already begun the process in Ventura County). Also, the CRS just completed an extensive parcel-by-parcel interview survey in Tulare County. Hence, it will not be necessary for us or the Avocado Commission to conduct a mail survey for over 75% of the total acreage. The status of the varietal information in Riverside and Santa Barbara County will have to be determined before any decision can be made on how to obtain the data in those two counties.

6.0 CONCLUSIONS

As a result of the three year project in cooperation with the California Avocado Commission and the Crop Reporting Service, we have arrived at the following conclusions:

1) The major problem with the California Avocado Survey data as provided by the various local and state agencies appears to concern San Diego County. It has become obvious that the San Diego County government does not rank agricultural surveys in the county as a high priority item. When the Crop Reporting Service conducts its quintennial survey the statistics are accurate. Over the succeeding four years the statistics deteriorate. In the current case the last survey in San Diego County was in 1972; that was the year that new avocado developments began at an annual rate of over 2,000 acres per year. The County Agricultural Commissioner, however, only estimated an annual increase of 1,000 acres per year. The existence of such problems in the reporting of agricultural data should alert the other agencies (CRS and the California Avocado Commission) to make allowance in the statewide estimates based upon other data available.

2) The other counties we are surveying appear to supply fairly reliable statistical reporting to the CRS. In Ventura County our results seem to be in accord with the annual growth rate of the county. Detailed review by the Crop Reporting Service in obtaining the varietal information will assist in the confirmation of this fact.

3) There are many areas in the state where the traditional ground survey techniques are now impossible because of inaccessible road networks in hilly country. Remote sensing not only appears to be the

most cost-effective method of detecting parcels that contain avocados, but may be in many cases the only method possible.

4) As a result of our investigation the California Avocado Commission has increased its 1980-81 production forecast by at least 12% initially. A second increase in the forecast resulted from the information derived from the packing houses. Consequently, the Commission has expanded its domestic advertising to increase sales and is vigorously pursuing the export market so that no fruit need be destroyed.

7.0 FUTURE STUDIES

Since the inception of this research project a question has been: Who will maintain the data once the project has been completed? As the project has progressed we have sought the assistance of the CRS for much-needed prior information in each of the counties. It has been through this participation that the CRS has become actively interested in the project and has been cooperating in the research. It is logical that the CRS receive the data resulting from this project and thus be able to update its files. Each agency will then be working from a common data base.

Another problem is to find a long-term solution for maintaining a current avocado acreage inventory, especially in San Diego County. Two solutions and possibly others need to be investigated. One solution is the further development of the techniques achieved by the research on this project and subsequent transferring of the techniques to the CRS. The other possible solution is for industry to provide a subsidy to the CRS to permit them to conduct a special avocado mail survey annually.

This is presently being done by the grape industry with a considerable degree of success at a reasonable cost. It is quite apparent that the state is not likely to provide more money for Fruit and Nut Crop Surveys than it has in the past.

To stretch the present survey money the Crop Reporting Service through the State Department of Food and agriculture will be cooperating with the UCR Agriculture Experiment Station remote sensing activities to develop a modified remote sensing survey technique that will eliminate or reduce the costly traditional Field Survey Program. The continuing NASA grant will be utilized to provide additional funding to transfer the techniques developed under the current avocado project to the CRS for use with all fruit and nut crops.

7.1 COMPLETION OF AVOCADO ACREAGE SURVEY

The California Avocado Commission's portion of the jointly funded Avocado Production Potential Research Project is funded through June 30, 1980. (Details of this project are reported in the Summary of Work Accomplished). Consequently the Riverside Campus researchers will be working on the completion of the avocado project the first two months of the new grant year.

In addition to encoding the data from the remaining counties to be inventoried there will be on-going studies to determine the capabilities of LANDSAT imagery for monitoring the expansion of avocado acreage. This study will be coordinated with the LANDSAT imagery studies being conducted for the CRS as described in the following paragraph. Image processing techniques will be employed. This study will differ from the CRS study in that an attempt will be made to discriminate avocado acreage from citrus and deciduous tree acreage.

7.2 DEVELOPMENT OF REMOTE SENSING TECHNIQUES TO IMPROVE THE CALIFORNIA FRUIT AND NUT CROP SURVEY PROGRAM

As a result of the avocado production potential work to date, the Riverside Campus group was approached by the CRS about the feasibility of extending the techniques used in the avocado study to include fruit and nut crops in general. This inquiry was motivated by the CRS's increasing difficulty in maintaining accurate fruit and nut acreage data in the face of rising costs and budgetary limitations. Last year, as was mentioned above, CRS spent $70,000 of its about $100,000 fruit and nut acreage survey budget to inventory one county, Tulare County. Under such circumstances, the likelihood of accomplishing an inventory of each of California's 58 counties at least once every five years in indeed small. Yet five years is the census interval CRS considers minimally acceptable.

Given this situation, the CRS has a vital interest in reducing survey costs. It is hoped that remote sensing methods can be used to identify fruit and nut acreage at a suitable level of detail. Additionally, the possibility of monitoring acreage changes via imagery is very attractive to the CRS. Such methods, if successful, could reduce expenditures on costly "windshield" field surveys and follow-ups.

The State Department of Food and Agriculture (CRS) has provided for a preliminary investigation of the remote sensing approach in Ventura County. The success in Ventura County has prompted the CRS to provide an additional $5,000 to further test the remote sensing techniques in San Diego County where the parcels are much smaller. We will be identifying all fruit and nut acreage in the county and providing the owner's name for each parcel.

In addition to performing the detection of each fruit and nut parcel we propose to analyze six to eight sequential LANDSAT scenes in order to establish a crop calendar that will permit the discrimination of tree crops from each other and from other types of vegetation. Both manual and automated interpretation techniques will be explored.

The minimum tree and vine crop parcel size that can be detected reliably will also be investigated. This knowledge is essential to the evaluation of LANDSAT imagery in terms of the CRS's requirements.

Methods for correlating image data to ancillary information will also be explored in light of the requirements of the CRS. The experience derived from the avocado study should be especially relevant to this aspect of the project.

The ultimate result of this project will be a set of specific recommendations, formulated in cooperation with the CRS, identifying the most effective approach to the incorporation of remote sensing techniques into the statewide quintennial Fruit and Nut Crop Surveys.

Should the Western Regional Applications Program at NASA-Ames be willing to support a U-2 CIR or DMSS overflight, additional effort would be directed at evaluating the merits of a high-altitude versus an orbital source of crop inventory data.

CHAPTER 5

SPECIAL STUDIES

ROBERT N. COLWELL

As previously mentioned in the present report, one of our team's major objectives under this grant is to help bring about the acceptance of modern remote sensing technology as a resource inventory and resource monitoring aid by those who seek to manage California's wildland resources. It follows that two measures of the success that we are achieving in this research at any given time are to be found in the answers that can realistically be given to the following two questions: (1) To what extent are various resource management agencies in California (and elsewhere) willing to replace NASA as the funders of our research? and (2) To what extent are such agencies converting to the new remote sensing-based technology that we are developing? For the period that is covered by this report some highly encouraging answers to these two questions can be given when it is recognized that one of the primary agencies that we seek to serve is the U.S. Forest Service. Consequently in this chapter, a brief description will be given of work that we are in the process of performing under auspices of that agency's Nationwide Forestry Applications Program (NFAP). All of the work can be considered to be a logical follow-on to work that we have recently performed under this NASA grant, as described in our 1979 and 1980 annual progress reports.

The primary study area within which we are conducting this Forest Service sponsored research is the Plumas National Forest within California's Sierra Nevada Mountains, but we have been told by Forest Service officials that they intend to sponsor similar work by our group on two other National Forests also, viz. Colorado's San Juan National Forest and Idaho's Payette National Forest. The title of our NFAP-sponsored research is "Evaluating Large Format Aerospace Systems for Coordinated Resource Planning". The term Coordinated Resource Planning is applied to certain cooperative efforts that are undertaken jointly by landowners and public agencies in order to improve the management of the land and its resources in a given geographic area. This type of planning is mandated by a 1975 Memorandum of Understanding which states that "the Bureau of Land Management, Forest Service and Soil Conservation Service will cooperate to the fullest degree possible in preparing and implementing resource management plans on operating units, allotments and other resource areas made up of intermingled or adjacent BLM and FS administered lands and privately-owned lands". Since a first step in developing such plans is that of obtaining suitably accurate inventories, and at suitably frequent intervals, the question logically arises as to whether the necessary inventorying and monitoring activities might best be done through the use of modern remote sensing technology and, if so, with what specific kinds of aerospace imagery. It was with a desire that we help answer this latter question that the Forest Service funded the study presently to be described.

The specific objective of our Forest Service-funded study was to determine the relative interpretability of various aerospace image type with respect to their usefulness for the identification and mapping of specific resource categories on a representative test area in California. The portion of California's Sierra Nevada Mountains within which these tests were concentrated is the NASA Bucks Lake Forestry test site in the Plumas National Forest, centered around the town of Quincy, approximately 50 miles southeast of Mt. Lassen.

The interpretability of these images was evaluated using three different kinds of photo interpretation tests: (1) non-stereoscopic study of 200 points on each of the seven images, (2) stereoscopic study of 120 points on the first six images, and (3) comparison of the delineations of resource boundaries as annotated on the last six images to delinations as annotated on the aeroneg color image. The interpreters used for these tests included 28 students who were at the time taking a course in forest photogrammetry and photo interpretation in the Department of Forestry and Conservation at the University of California, Berkeley.

Based on the results of the first two tests, our group concluded that the large-scale aeroneg color and black-and-white imgaes are significantly more interpretable than the image types obtained form the high altitude platforms. With the exception of the LFC color photography, which had an extreme bluish cast, the interpretability ratings of the various image types obtained from the U-2 aircraft were not statistically different, one from another, and could be used interchangeably.

Although the overall percent correct values were required to rank the image types with respect to relative interpretability, the quality of the information present on the respective image types is best evaluated by the performance of the "best" photo interpreter. We think that a skilled photo interpreter who is familiar with a particular forest environment should be able to identify the resource present with an accuracey of 80 to 90 percent on any of the six aircraft image types and with an accuracy of 40 to 60 percent on the Landsat image type, depending upon the complexity of the classification systems employed.

Because of the significance of these findings the following additional details are provided with respect to the test site that we selected and the imagery that was acquired of it.

There are three primary reasons why this geographic area was selected as a NASA Test site nearly two decades ago, and why, therefore, personnel of our Remote Sensing Research Program have so used it ever since:

(1) There is an unusually great variety of conditions encounterd within the area in terms of vegetation, geology, soils and hydrology.

(2) During a long period of time, "ground truth" with respect to all of these resource-related attributes has been accumulated for this particular area to a most unusual extent. This is occasioned by the fact that, for more than 50 years, the Bucks Lake area has served as the instructional site for the University of California's Forestry Summer Camp. During that long span of time, each professor who has been involved in providing instruction to forestry students has first made his own observations in the field and in this way has added his own bit of authoritative information with respect to certain attributes of the area, and

(3) It was evident, even from the outset, that most of the area would be little altered by man's developmental activites apart from his conduct of normal logging operations and related forestry activities (including reforestation, erosion control, etc.). This prediction proved to be correct. Hence, unlike many other areas, this one remains relatively undisturbed, with the result that earlier photos and associated ground truth still are highly useful.

Elevationally, the test area ranges from 3500 feet to 7200 feet above sea level. It has an areal extent of approximately 400 square miles.

The following two important preliminary steps were taken as a result of arrangements that were made with NASA by Dr. Frederick P. Weber, Manager of the Nationwide Forestry Applications Program:

(1) Through the use of U-2 aircraft, flights were made from Moffett Field (adjacent to the NASA Ames Research Center, California) on August 26 and 28, 1980 to obtain representative high altitude photographs with the Optical Bar Camera and with three Large Format Cameras, respectively, of our test site and

(2) excellent reproductions of all of this photography, in opaque print form, were made at a scale of 1/24,000 by NASA's Manned Spacecraft Center in Houston, Texas. Three other image types also were included in these interpretability tests, as summarized in Table 1.

TABLE 1. TABULAR SUMMARY WITH RESPECT TO THE SEVEN PRIMARY IMAGE TYPES THAT WERE USED IN THE PLUMAS NATIONAL FOREST INTERPRETABILITY TESTS.

Kind of Camera or sensor	Kind of Print or Imagery	Approx. Flight Alt. above the terrain	Approx. scale at which interpreted
Optical Bar	Color IR (SO-131)	65,000 feet	1/24,000
Large Format (9" x 18")	Color IR (SO-127)	65,000 feet	1/24,000
Large Format (9" x 18")	Natural Color (SO-242)	65,000 feet	1/24,000
Large Format (9" x 18")	Panchromatic Black & White (PanX-3400)	65,000 feet	1/24,000
Zeiss, 8¼ fl (9" x 9")	Aeronegative Color	16,000 feet	1/24,000
Zeiss, 8¼" fl (9" x 9")	Aeronegative Black & White	16,000 feet	1/24,000
Landsat, Multispectral Scanner	Simulated Color LR composite *(Geopic-enhanced)	570 miles	1/100,000

Based on guidance provided by U.S. Forest personnel, both on the Plumas National Forest and within the NFAP, ten forest resource-related categories were used in these tests, as summarized in Table 2.

TABLE 2. LISTING OF THE TEN CATEGORIES OF FOREST COVER OR OTHER "LAND USE STATUS" THAT WERE USED IN THE PRIMARY INTERPRETABILITY TESTS THAT WERE CONDUCTED ON THE PLUMAS NATIONAL FOREST, CALIFORNIA

CATEGORY	ABBREVIATION	CATEGORY	ABBREVIATION
Conifer	C	Grass	G
Conifer/Hardwood	C/H	Rock	R
Hardwood/Conifer	H/C	Water	W
Hardwood	H	Agriculture	A
Shrub (Brush)	S	Other (rural, industrial urban and bare ground)	O

Finally, based on the results of our preliminary mapping study, we have concluded that the high resolution aeroneg image types (both color and black-and-white) are again best, in this instance for mapping the actual boundaries of resource features.

As previously indicated, it is on the basis of their high degree of satisfaction with our work that personnel of the NFAP of the U.S. Forest Service have agreed to fund work of a similar nature by our group on two other National Forests, viz. on Colorado's San Juan National Forest and on Idaho's Payette National Forest. Already Forest Service personnel are making good use of our findings as they proceed with their various inventory, mapping and monitoring projects. For this reason we consider this to be a good example of our having achieved certain "technology transfer" objectives of the NASA-funded project that is dealt with in this report.

CHAPTER 6

PROJECT SUMMARY

Robert N. Colwell

Note: Because of the lengthiness of this Annual Progress Report, it has been deemed desirable to conclude it with a chapter-by-chapter summary. Even though the present chapter is intended to be no more than a summary, the highlighting of certain relevant details is considered necessary if the essence of each phase of our multicampus work under the grant is to be adequately grasped. Herein lies the explanation for the fact that even this summary chapter is a rather lengthy one.

Chapter 1 of this progress report first sets forth the rationale for applying modern remote sensing technology to selected problems in California. Consideration is then given to the means by which research teams such as ours can help bring about the acceptance of such technology by those who manage California's natural resources. Consistent with our goal of gaining technology acceptance, the overall objective of work done under this NASA grant is to demonstrate, by means of specific case studies, that information about natural resources as derived through the use of modern remote sensing techniques can lead to the development and implementation of more intelligent measures for resource management than would otherwise be possible. While all of our case studies, already described in Chapters 2, 3, and 4) deal with applications that can be made of remote sensing in California, virtually all of our findings are considered to be applicable in many other geographic areas also. Chapter 1 concludes with (1) the reminder that our primary goal under this NASA grant is to bring about the acceptance and adoption of modern remote sensing technology by California's resource managers and (2) the highlighting of specific instances in which that goal is being achieved. In each instance emphasis is placed on the fact that action either is now being taken, or soon will be, by the resource managers, themselves, based primarily upon the remote sensing-derived information.

As indicated in Chapter 2, the Berkeley Campus directed its research efforts to the following 5 activities during the present reporting period: (1) The Quantification of Wildland Fuels in Mendocino County, with a view to providing remote sensing-derived information that would lead to a substantial alleviation of that county's wildland fire problem; (2) An experiment known as the "Forsythe Planning Experiment" which is attempting to maximize the usefulness of inputs from Landsat and from geographic information systems to planning processes in Mendocino County; (3) The development and evaluation of a digital spectral/terrain data set for "Coordinated Resource Planning" in Colusa County; (4) The Mapping of Wildland fuel hazards in Shasta County through a suitable modification of the remote sensing-based methods which personnel of the Berkeley RSRP had developed previously for use in Mendocino County; and (5) The construction and preliminary analysis of a "Digital Data Bank" for California's Big Basin State Park in Santa Cruz County.

As documented in the 5 reports of Chapter 2 that deal, respectively, with the above 5 topics, both our remote sensing scientists and the agencies whom they seek to serve agree that they are, in each case, progressing rapidly toward acceptance and adoption by those agencies of remote sensing technology for the stated purposes.

Chapter 3 documents the fact that the Santa Barbara campus concentrated its research efforts on the following two activites during the present reporting period: (1) Scene Analysis for Wildland Fire-Fuels Characteristics Using Landsat and Collateral Data, and (2) Determining the Feasibility of Using Remote Sensing Techniques to Detect Salinity-Related Cotton Canopy Reflectance Differences.

The Scene Analysis studies entailed a cooperative effort by the UCSB remote sensing scientists with personnel of (1) the California Department of Forestry, (2) the California Office of Emergency Services, and (3) the U.S. Forest Service under a federally mandated program known as Operation FIRESCOPE, the acronym for Firefighting Resources of Southern California Organized for Potential Emergencies. The study was concentrated on chaparral vegetation within a 7½-minute quadrangle in the inland foothill mountains northeast of Los Angeles in the Angelus National Forest.

In this study it was recognized at the outset that the rate of spread of a forest fire depends upon the integrated effects of fuel characteristics, terrain attributes, wind speed, wind direction and atmospheric humidity. Efforts were concentrated on the derivation of fuel characteristics from remotely sensed data. Among these characteristics are spatial continuity, branching habit, size class distribution of the biomass, total and standing biomass and the ratio of living to dead plant material. Landsat MSS data was used in an automated classification procedure to produce vegetation type and density labels.

Because of the success already achieved in this effort, the Forest Service has asked UCSB to propose a cooperative agreement to further develop a fuel data base for the entire 7-county FIRESCOPE area.

In the salinity-related Cotton Reflectance Studies one objective was to determine whether ground-based in situ radiometer data, as obtained at weekly intervals with a hand held spectral radiometer, could be used to make qualitative and/or quantitative assumptions about cotton grown under different salinity irrigation treatments. (The test area was in California's San Joaquin Valley) If so, then presumably it would be possible to make similar vegetation related inferences from multispectral aerospace acquired imagery. Initial results show a general trend of decreased reflectance with increased salinity contents in the irrigation treatment. The relation between vegetation reflectance and the factors which affect it (salinity treatment, plant height per cent ground cover, etc.) currently is being investigated through the use of multiple regression and correlation procedures.

As documented in Chapter 4, the Riverside campus continued its efforts during the present reporting period, to employ remote sensing as an aid to California's rapidly growing avocado industry. In addition it sought to improve methods currently being used by the California Crop and Livestock Reporting Service in making its annual Fruit and Nut Crop Surveys.

In the Avocado Survey studies, efforts have been concentrated upon the completion of a study designed to develop remote sensing-aided techniques for obtaining avocado crop acreage data. That effort continues to be funded in part, by the California Avocado Commission. Methods that the Riverside remote sensing scientists had previously developed for San Diego County are now in the process of being tested in Ventura County, with final testing to be accomplished in Santa Barbara and Riverside Counties. It now is apparent that conventional methods have been under-estimating avocado acreage by as much as 30 per cent thereby accounting for the fact that efforts to market the crop were often inadequate in relation to the total size of the crop that was to be marketed.

In the Fruit and Nut Crop Surveys, which have only recently been started, the Riverside remote sensing scientists are using, with significant initial success, essentially the same techniques as they previously had developed for making avocado acreage surveys.

As in each of our previous annual progress reports under this grant Chapter 5 of this report deals with "Special Studies" and describes work that we are doing as a follow on to certain of our NASA-funded work, but under different auspices. The Special Study that is dealt with in this year's report features work that we have completed recently under auspices of the U.S. Forest Service as a logical follow-on to work that we had previously performed under this NASA grant on California's Plumas National Forest. The follow-on work in this instance has been funded by the U.S. Forest Service under its Nationwide Forestry Applications Program and is entitled "Evaluating Large Format Aerospace Systems for Coordinated Resource Planning". The specific objective of this Forest Service-funded project was to determine the relative interpretability of various aerospace image types with respect to their usefulness for the identification and mapping of specific resource categories on a representative test area in California. Based on our results to date in performing this study, the Forest Service has agreed to fund work of a similar nature by our groups on two other National Forests, viz. on Colorado's San Juan National Forest and on Idaho's Payette National Forest. Furthermore

Forest Service personnel already are making good use of our findings as they proceed with their various inventory, mapping and monitoring projects. For this reason we consider this to be a good example of our having achieved certain "technology transfer" objectives of the NASA-funded project that is dealt with in this report.

Work that we propose to perform during the coming year under this grant was detailed in our semi-annual progress report dated December 31, 1980.